

# NIMBUS PROGRAM HISTORY



*National Aeronautics and Space Administration  
Goddard Space Flight Center*

## **NIMBUS PROGRAM HISTORY**

### **EARTH-RESOURCES RESEARCH SATELLITE PROGRAM**

**OBSERVATORY OPERATIONS  
1964-1994**

**EARTH SCIENCE RESEARCH  
1964-2004**

*October 26, 2004*

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FOREWORD

August 28, 2004 commemorated the 40th anniversary of the launch of the Nimbus-1 Earth observation satellite. This occasion represents an opportunity to recognize the benefits to the world community resulting from the increased knowledge of the Earth’s atmospheric environment, weather, oceanography, and other geophysical properties of the earth’s structure derived from the National Aeronautics and Space Administration (NASA) Earth observation satellite programs managed by the Goddard Space Flight Center (GSFC). Starting in 1964 and for the next twenty years, the Nimbus platform was the country’s primary Earth science remote-sensing research and development satellite platform; seven satellites launched over a fourteen-year period, operated over a thirty-year period. The archived large, multi-year, multi-discipline Nimbus data sets were invaluable for Earth science research, which continues on. Each Nimbus spacecraft carried instruments that demonstrated new techniques for measuring the Earth’s meteorological and environmental behavior, and composition. This technology was transferred to the National Oceanic and Atmospheric Administration’s (NOAA) new operational satellite instrument designs. The Nimbus research results were applied to NOAA’s application systems, resulting in new tools and processes for weather forecasting, environmental monitoring, and Earth resources assessment. This technology was transferred to NASA satellites; the heritage of instruments on most Earth-resources satellites launched over the past three decades can be traced to Nimbus instrument technology and/or scientific accomplishments.

Reliable, long-term weather forecasting and hurricane warnings are governmental services that the public depends on for their safety and are important to many commercial operations. The governmental search and rescue service provided to small aircraft downed in remote areas or to private small boats in distress in isolated areas is a lesser-known governmental service that is of critical importance to the families of the persons whose lives are saved by this service. Monitoring large oil spills to aid in controlling the environmental impact to threatened shorelines and fishing areas, and monitoring forest fires to aid in their containment are other timely services expected from the government. The ozone layer in the stratosphere protects humans against extreme ultraviolet exposure that causes skin cancer. The world community took environmental control steps to protect the ozone layer after Nimbus data confirmed that the protective layers of ozone over the Antarctic and some highly populated areas of the world were being degraded. The data also revealed that very large size holes (amounts of ozone below what is normal and considered safe values) existed in the stratospheric layer of ozone over these areas. That long term monitoring of the stratospheric ozone is required to determine if additional protective measures are required is a little known governmental service being provided. This can become critical to those living in areas that become unprotected from the sun’s ultraviolet radiation because of a future significant degradation of the ozone layer. All of these services resulted from the Nimbus Project that developed experimental satellite instruments for measuring the behavior of the Earth’s components and environment, enabling and advancing atmospheric, oceanographic and global change science research programs. The Goddard

Space Flight Center (GSFC) in Greenbelt, MD, the NASA lead Center for earth-science research, conducted this Nimbus Program from 1964-1994. Current Earth science research continues to use this unparalleled long-term, multi-spectral, and multi-application Nimbus database.

There is a continuing need to conduct scientific research to improve the understanding of the Earth’s atmospheric, terrestrial, and oceanographic dynamic behavior. This research explores methods of improving the governmental services being provided and identifies additional services of value to the public. Equally important is the need to extend the database of these physical parameters central to developing an improved understanding of the Earth’s energy balance and ocean productivity that impact global climate change. The NASA/GSFC Earth Observing System (EOS) Program, with three satellites launched over the past five years, is a major effort to facilitate this scientific research. The EOS science program will contribute to the investigations of many of the pressing questions that derived from the Nimbus science program.

There were many contributors to the success of the Nimbus Program. The remote sensing advances and the scientific research that enabled the societal benefits to materialize is attributable to the GSFC and other government and university scientists who had the vision to sponsor the new Nimbus experiments. They spearheaded the productive scientific efforts that were supported by a broad-based science community.

The public, in general, is not aware of the NASA connection to the origin and quality of the services described above. This lack of recognition was exemplified by this quote by a Congressman being briefed in 1983 on the capabilities of a proposed new class of NOAA satellites for improved weather forecasting based on the Nimbus Project’s meteorological instrumentation achievements. *“What do we need satellites for when we can see pictures of the weather on TV?”*

The objective of this paper is to commemorate the fortieth anniversary of the launch of the first Nimbus satellite, illuminating the societal and scientific benefits derived from the NASA Goddard Space Flight Center Nimbus research satellite program devoted to understanding the Earth’s behavior.

Ralph Shapiro  
Nimbus Operations Manager  
1963-1980

**PROGRAM OVERVIEW**

*Program Initiation*

The development of the initial Television Infrared Observation Satellite (TIROS) was assigned by DARPA to the Army Signal Corps, with RCA as the implementation contractor. The TIROS project was transferred to NASA and the design team of Stroud, Stampfl, Licht, Hanel, Bandeen, and Nordberg transferred to GSFC to take on the TIROS responsibility. GSFC launched and operated this first meteorological satellite on April 1, 1960. The data was sent to the Weather Bureau semi-operationally. This spin-stabilized satellite, designed and built for NASA by the RCA Corporation Astro-Electronics Division in Hightstown, NJ, ushered in a new era in meteorological observations; large-area pictures of clouds taken by spacecraft high above the clouds became available. A short period later, after this capability’s value to the U.S. Weather Bureau was recognized, the Environmental Satellite Service Administration (ESSA) was established to operate the TIROS satellites under a federal charter of responsibility for civilian application/operational satellites. ESSA and the successor National Oceanographic and Atmospheric Administration (NOAA) of the Department of Commerce established a relationship that continues today, whereby NASA managed the building of a series of constantly improving meteorological satellites to ESSA/NOAA specifications, and tested and launched the satellites that ESSA/NOAA operated.

In 1959, Bill Stroud and Ed Cortright, a NASA Headquarters program manager, toured the country sounding out interest in a follow-on research satellite. Out of this effort, Bill Stroud developed the specifications for the design objectives of a new research satellite, named Nimbus by Ed Cortright. T. Keith Glennon, the first NASA Administrator, approved the Nimbus Project as an R&D program.

*Initial Design*

The GSFC Nimbus Project, initially established as an R&D Project, was tasked to build the Nimbus spacecraft to serve as the ESSA operational spacecraft replacing the TIROS experimental meteorological satellites operated by ESSA. ESSA helped fund the Nimbus development. The Project was reverted to the NASA Earth remote sensing research Project in 1963 after development failures induced ESSA to drop their support of the Nimbus Program.

Nimbus, named after the Latin word for rain cloud, was originally conceived as a GSFC in-house satellite development Project. Bill Stroud led the Project development that started in 1959. John Licht was the designer of the Nimbus spacecraft architecture: earth viewing, an attitude control concept for achieving three-axis stabilization, (previous spacecraft were spin stabilized.), solar panels that tracked the sun, and a platform structure (sensory ring) with compartments designed to accommodate new configurations that housed instruments and electronic boxes. Dr. Rudolf (Rudy) Stampfl was the system designer who conceived the spacecraft bus concepts and the active cooling system for the electronics and small instruments installed in the sensory ring. The complex attitude control system that applied a combination of 3-axis reactive momentum wheels and the inherent gravity-gradient stabilization to provide 1° 3-axis attitude control with low-jitter represented a major development challenge. This fine attitude control requirement was necessary to be able to accurately locate the high-resolution scientific data that was planned. A large three-axis stabilized air-bearing platform was conceived for dynamic testing of the attitude-control system. The General Electric (GE) Company in King of Prussia, PA was contracted to develop, build, and test the attitude control system. GE was also contracted to build the structure and serve as the Observatory integration and test contractor.

*Spacecraft Design*

Figure 1 is a detailed drawing illustration of Nimbus-7, which has the structure common to all Nimbus Observatories. It shows the location of various elements of the spacecraft, including the complement of nine experiments. The wings are panels of solar cells that generate the required power to operate the spacecraft, sized to provide power for the expected lifetime of the spacecraft and taking into account Earth-sun relationships and cell degradation. The panels track the sun the during satellite daylight portion of the orbit, converting sunlight into electrical power for operating the Observatory. This sun-tracking arrangement (a first) provides more productive power generation per cell than comes from cells fixed to a spacecraft body. The 10-foot tall satellite design separated the attitude control system (on top) from the 5-foot diameter sensory ring (bottom). The platform batteries and platform and instrument electronics are installed in the sensory ring, which is divided into 14 compartments. The instruments and antenna are mounted under the sensory ring and in the

open central core of the ring. The three-axis stabilization, earth-pointing attitude control system (a technological first for civil spacecraft) maintained the attitude within one degree, with low jitter.

The structure and thermal control system designs proved to be extremely effective in support of the multi-mission Nimbus program that materialized. It accommodated seven different instrument manifests (as many as 9 instruments per spacecraft) with minimum structural changes while providing the required viewing and thermal control requirements. After the first spacecraft, this provided an extremely favorable payload to spacecraft funding ratio compared to other spacecraft programs; on Nimbus-7 with a new complex instrument mission it was 1.6 compared to 0.2-0.5 for typical new spacecraft programs. This accommodative Nimbus platform enabled the new earth-resources Landsat satellite program to be undertaken with low platform development costs. Landsat 1,2,and 3, which demonstrated the utility of what became major NASA and commercial satellite programs, used the Nimbus structure and the temperature control, power, attitude control, telemetry, and command subsystems for its platform.

The original Nimbus satellite design life expectancy was 6 months. (Nimbus-1 lasted 28 days, but Nimbus-2 and 3 actually operated for 2 1/2 years.) An increased understanding of the impact of the space environment on the satellite components led to improved space-hardened electrical components and improved lubrication techniques. Starting with Nimbus-4, the incorporation of these measures, the application of more conservative electrical designs, and the incorporation of redundancy of critical components increased the lifetime expectancy for the later satellites to five years. The spacecraft lifetime of the last four Nimbus spacecraft ranged from 6 to 15 years. Except for two instruments with cryogenic coolers that had a 6-month design life, and the Filter Wedge Spectrometer that never functioned properly, the instruments also had lifetimes ranging from 6 to 15 years.

The satellites operated in a 12-noon, ascending node (i.e., crossed the equator northbound at 12:00 noon, local time), near-polar sun-synchronous orbit, at a 500-600-mile altitude that resulted 13-14 orbits per day. This sun-synchronous orbit, a first for meteorological satellites, provided day and night local area coverage every 24-hours, repeated at the same time daily. This provided temporal

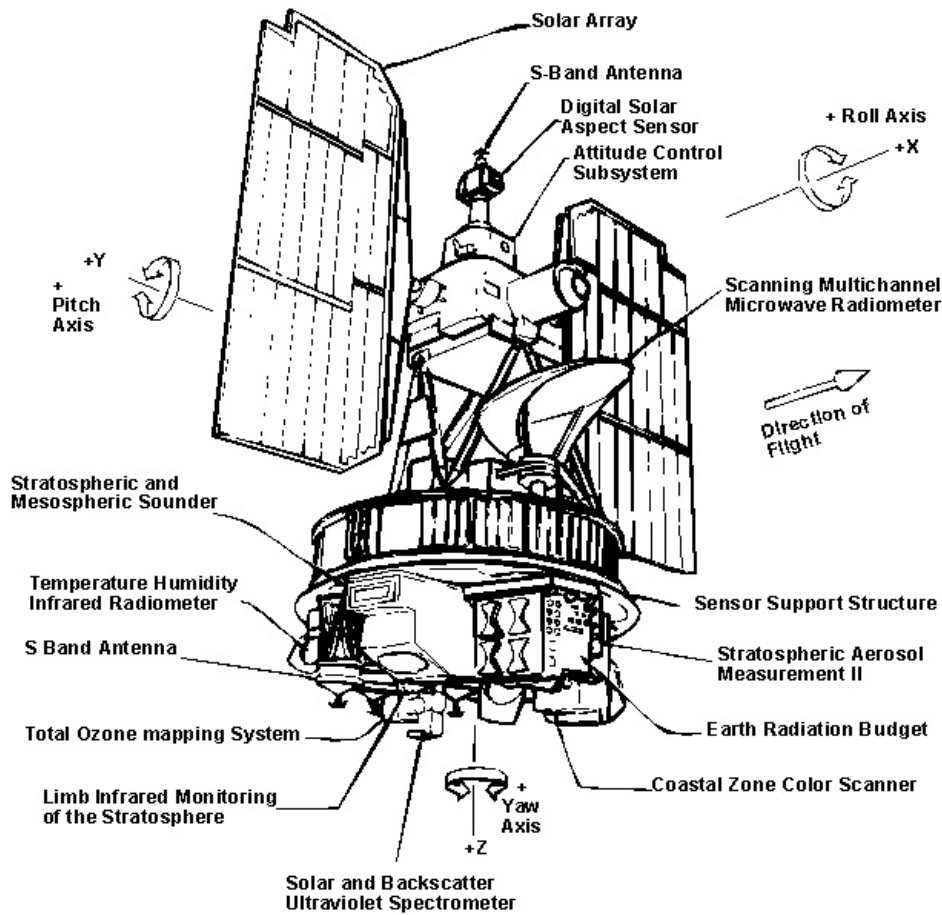
and spatial data covering the globe, which was very beneficial for weather forecasting meteorological models; this type of orbit became the norm.

The Nimbus satellites were launched from the NASA Western Test Range at the Vandenberg Air Force Base in Lompoc, CA. They were launched in a southerly direction at midnight so that they would cross the equator going northbound at local noon halfway around the world. Launching this way at this site effectively placed the spacecraft directly into the required orbit plane, resulting in a reduced launch vehicle propulsion burden and allowed using a smaller launch vehicle than would be required for a launch at the Kennedy launch site in Florida which doesn't allow for launching directly south.

### *Program Migration From Operational to Research Meteorological Satellite*

Originally intended to be an operational meteorological satellite concerned primarily with providing atmospheric pictorial data for improved weather forecasting, Nimbus became the premier Earth research satellite that provided atmospheric temperature measurement data for improved weather forecasting until the equivalent data was available from operational satellites. The Nimbus Program received several spacecraft development setbacks in 1963, the year scheduled for the first launch. In addition, the air-bearing test platform concept for dynamically testing the attitude control system became an expensive, developmental nightmare and was dropped; no dynamic testing of the ACS was performed. When a one-year launch delay became necessary to remedy the design problems, NOAA dropped out of the Nimbus relationship with NASA and planned on a new class of TIROS satellites, still managed by NASA and built by RCA. NASA decided to continue to build the Nimbus-1 satellite and operate it as a research satellite and as a pseudo-operational satellite providing the Weather Bureau with high quality cloud cover data taken globally.

Nimbus-1 was launched on August 28, 1964. Twenty-eight days later it suffered a catastrophic failure when the ball bearing in the small motor driving the solar arrays failed; the commercial motor used had a faulty thermal design that caused overheating and the bearing grease dried out. In its short one-month lifetime, the first Nimbus observatory had a major impact on the world's future meteorological satellite programs. It demonstrated the value of high quality cloud pictures for weather analy-



**Figure 1: Nimbus 7 Observatory.**

sis and hurricane tracking and of full Earth coverage for global cloud system analysis. Perhaps most importantly, it demonstrated the merit to meteorological applications of a sun-synchronous polar orbit that produced daily, repeatable-time, global-area coverage compared to the non-repeatable time, limited-area coverage of the TIROS 50° inclination orbit.

Though brief, the scientific success of Nimbus-1 provided a foundation for a GSFC proposal to NASA Headquarters for the continuation of the Nimbus Project as an intensive remote sensing research and development Project. Harry Press, the Nimbus Project Manager, led a three-month intensive Program planning and presentation effort. Dr. William (Bill) Nordberg, the Nimbus Project Scientist developed the long-term scientific objectives (e.g., atmospheric temperature measurements for improved weather forecasting, use of microwave spectrum instruments to see through clouds and measure rainfall, a system for tracking animals and remote platform data collection and location) and the science and engineering team developed

the science plan and instrument implementation plan. With the support of GSFC Center management, the programmatic/scientific benefits were presented to Charles (Chuck) Mathews, the NASA Associate Administrator for Applications. Headquarters approved Nimbus-B as an experimental meteorological research satellite with a 9-instrument complement that included the first capability to measure atmospheric temperature quantitatively from space that revolutionized meteorology. Because of the 2-year period required to build the new instrumentation, Headquarters also approved Nimbus C (designated Nimbus 2 after launch) to provide data for continued earth science research from a satellite that could be built more rapidly and inexpensively than the new Nimbus-B. Nimbus-2 was built and launched approximately one year after approval using the prototype AVCS and APT instruments from Nimbus-1, the MRIR instrument that was planned for Nimbus-1 but wasn't ready when Nimbus-1 was launched, and the HRIR instrument that was available from the original multiple-copy Nimbus-1 plan.

The Nimbus-B Observatory was built, tested and readied for launch within schedule. However, it was destroyed after liftoff along with the launch vehicle when the launch vehicle veered off course due to the launch vehicle attitude control system malfunction that required the launch site Safety Officer to destroy the vehicle. It crashed into the ocean; the nuclear RTG experiment containing plutonium pellets onboard the spacecraft was recovered from the ocean floor intact, relieving the concern about possible environmental contamination. The malfunction was due to human error. The launch vehicle gyroscope removed for diagnostic testing during the launch countdown was reinstalled backwards; the technician ignored the dowel-keying alignment arrangement. It was determined that the high gyroscope signal levels that prompted the emergency maintenance were due to the high winds and not to a degraded gyroscope. A replacement Observatory, Nimbus-B2 was authorized and built within a year, and was launched successfully to become Nimbus-3.

Project Management

The Nimbus Project conducted the Observatory design and development management in a distinctive manner compared to the other large Observatory Projects conducted at GSFC, which essentially assigned the Observatory design and development implementation responsibility to their prime contractor. The Nimbus Project retained the full responsibility for the Observatory design and development; this applied to all Nimbus Observatories. The Nimbus Project directly contracted for all of the Observatory elements; the Observatory integration and test (I&T) was contracted to the General Electric Corporation, with some directed subcontracts.

Nimbus Project technical management personnel were assigned the overall responsibility for the Observatory development and integration and test (I&T). GSFC Engineering Directorate subsystem and discipline engineering personnel were assigned individual responsibility for the design and development of the various elements of the Observatory, including the platform structure, the subsystems, instruments, flight software, launch vehicle interface, and launch operations. This process of full accountability retained by the GSFC personnel had very beneficial programmatic results. Except for the setbacks in the program attributable to lack of prior experience in addressing challenges unique to operating in the space environment that impacted Nimbus-1 and the FWS

instrument on Nimbus-4, the Nimbus Observatories met or exceeded the Project objectives and performance requirements. Through close monitoring and coordination with their respective contractors, and with their accountability responsibility, the Technical Officers were in a position to quickly resolve technical issues, control the subsystem development schedule to within the overall program schedule, and to control and contain costs.

The Nimbus Project also handled the management of the spacecraft operations differently. For all the Nimbus Observatories, starting with Nimbus-1, Control Center operations responsibility was retained by the Nimbus Project as opposed to the customary approach of assigning the responsibility to a GSFC-wide spacecraft operations contractor. Nimbus operations, managed by Project personnel, had an extremely successful record. For thirty years, General Electric Corporation (GE) contractor personnel efficiently conducted the mission operations, effectively scheduling the Observatory operations to meet the mission requirements within the changing constraints of aging spacecraft. They managed the spacecraft operations and health in a manner that contributed to the longevity of the Nimbus Observatory operations. General Electric personnel also developed the Control Center operations software and the software for the operational data processing conducted in the Nimbus Data Handling System (MDHS) in GSFC Building 3 that was operated by the Mission and Data Operations Directorate. A major accomplishment was their development of the software required to process, display, and analyze the telemetry data, and generate the Observatory commands that operated in a desktop PC. This accomplishment, ten years before the end of Nimbus operations, contributed significant savings by eliminating the operation and maintenance cost associated with operating the old and obsolete large computer equipment that was a carryover from Nimbus-1. This accomplishment was vital to the continued funding of Nimbus operations and served as a model for other GSFC satellite control centers.

Project Goals and Accomplishments

After the Nimbus Project fallout with ESSA, Nimbus was established as NASA’s experimental meteorological satellite Project. The breadth and quality of the scientific studies devoted to the Nimbus data, and the new satellite programs that stemmed from Nimbus testifies to the successful accomplishment of this NASA Headquarter goal

Nimbus	Objectives and Goals	Accomplishments
A (1)	Three-axis stabilized, earth-pointing Observatory Sun-synchronous orbit, new for meteorological satellites High quality daytime cloud pictures Nighttime cloud pictures	The 3-axis stabilized ACS worked extremely well to the benefit of the science data Sun-synchronous orbits became the norm for the operational meteorological satellites The ability to present Nimbus local cloud pictures on TV became an instant success.
B1 (*)	Convert to an experimental meteorological satellite program; expand science scope To advance the quality of weather forecasting with instruments that quantitatively measure atmospheric temperature * Nimbus B1 launch failed; number not designated	Carried 9 experiments, 28 spectral channels Nimbus expanded into the infrared spectra with IRIS for measuring atmospheric species Nimbus expanded into the solar radiation and animal tracking fields; demonstrated platform location from satellite communications SIRS improved weather forecasting models
B2 (3)	Replicate B1 Observatory within 1-year Keep B2 implementation costs within \$20M	B2 was launched within 1-year after approval The cost was within the \$20M budget
C (2)	Replicate Nimbus-1 and add MRIR within 1-year Keep Nimbus C development costs below \$10M	Nimbus C was launched within 1-year Nimbus C cost \$8.5M
D (4)	Incorporate spacecraft improvements to accommodate expanded instrument data streams, provide finer attitude control, and increased ACS longevity Expand meteorological measurement fields	New ACS provided greater stability New ACS features used to extend satellite operations on later Nimbus Observatories Expanded into the ultraviolet spectra with BUV; BUV data confirms ozone photochemistry theory SCR introduced stratospheric measurements
E (5)	Expand Nimbus science to include disciplines supported by microwave instrumentation Expand science to include terrestrial applications Develop an atmospheric temperature sounder that serves as a prototype for the NOAA sounder	NEMS introduced microwave sounders for measuring atmospheric temperature in the presence of clouds. ESMR introduced microwave scanners for mapping rain and land and sea ice properties from space ITPR was the prototype for the NOAA VTPR; ITPR data sent routinely to NOAA facilitated rapid VTPR incorporation into operations SCMR introduced the identification of mineral resources from space
F (6)	Develop instrumentation that increase the quality of weather forecasting Develop Earth limb measurement technology Include instrumentation to support wind studies and climatology	Included three instruments that enhanced weather forecasting; HIRS for temperature measurements across the swath; SCAMS for O <sub>2</sub> and water vapor profiles; PMR for stratospheric temperature and species TWERLE supported equatorial wind studies; it prompted the SARSAT program development LIMS demonstrated the technology to make low signal level measurement of the Earth’s limb
G (7)	Expand science to include oceanography Make concentrated measurements of stratosphere Expand science community participation in the science data development process Make science data more readily available to user community	CZCS opened up the field of ocean productivity research using satellite data SMMR first to make more precise all-weather observations of both global sea ice concentrations and type (age) and sea surface temperatures Four instruments measured stratospheric species, LIMS. SAM II, SAMS and TOMS TOMS measured total ozone in the atmosphere; revealed the ozone holes in the stratosphere and exposed its dangers; ushered in the 25 years of TOMS measurements Eight Nimbus Experiment Teams collaboratively developed data products and their processing algorithms

Table 1: The Nimbus Program fulfilled its goals; the accomplishments benefited mankind.

for the Nimbus Program. The government services applications that derived from the Nimbus experiment program to the benefit of mankind were unanticipated and represent another large measure of the Nimbus Project success. The ability to build a large Observatory that would last more than 2-years, an inability faced by other GSFC observatories, including the early Nimbus Observatories, was more than adequately demonstrated by the Nimbus Project.

The Nimbus Project committed to different objectives and goals that were commensurate with the programmatic and technical challenges associated with each Observatory. A summary of the objectives and goals, and the respective accomplishments for each Observatory is provided in Table-1.

*Program Participants*

A major success factor in the Nimbus Program was the effective 20-year partnership that existed between the government managers and engineers that managed the program and the over 40 industrial companies that built the satellite equipment and instruments. Designs met performance requirements, individual element schedules were adhered to without impact to the overall integration schedule, and costs came in at or below the rather slim cost estimates for the challenging deliverables.

Two companies were major participants in the Observatory design and development effort. The General Electric Corporation in King of Prussia, PA built the spacecraft structure and the attitude control system, integrated the Observatory and conducted the critical, complex environmental testing that validated the Observatory readiness for launch. The RCA Corporation Astro-Electronics Division in East Windsor, NJ built the spacecraft power systems, spacecraft camera systems, spacecraft communication electronics, high data rate tape recorders, the ground RF signal demultiplexers, and the ground system for converting the visible camera electrical signals into film pictures. A General Electric team of engineers, technicians, and software programmers operated the Nimbus Control Center for thirty years.

Many national and international organizations participated in the experimental aspect of the Nimbus Program. They sponsored and/or managed experiment development programs. (e.g., SIRS and ITPR by ESA; ERB by NOAA; HIRS by NOAA and GSFC; LIMS by NCAR

and LaRC; PMR and SCR by the UK Oxford University; NEMS and SCAMS by JPL; RTG by the Atomic Energy Commission; and SAM II by LaRC. Universities that participated in experiment development activity include the University of Wisconsin, the University of Florida, MIT, and the UK Reading University.

The day-by-day work effort over this 20-year Nimbus development period was a collective effort between GSFC personnel and the external resources supporting the program. The GSFC engineering staff managed the satellite development; private industry contractors built the satellites. GSFC operations personnel managed the flight operations conducted by private contractor personnel. GSFC and external institutional scientists collaborated in the development of the algorithms to convert the instrument measurements into geophysical parameters and analyzed these parameters to deepen our understanding of the Earth’s behavior and of the natural and man-made environmental phenomena. Their collective research efforts resulted in the Nimbus applications of the science data identified in this document. Their conclusions and quest for more types of data to fill the gaps in their analyses provided the basis for new satellite experiment proposals to measure other characteristics of the Earth’s atmospheric and geophysical behavior that were incorporated in future satellite missions.

*Significant Contributors*

The Nimbus program addressed and met the programmatic challenges successfully. They could not be achieved without these individuals who made significant contributions to various aspects of this long and complex program.

**Program initiation and project development:** William Stroud essentially established the application of satellites as a branch of meteorological research. He organized the GSFC Aeronomy and Meteorology Division that conducted the initial scientific research that demonstrated the value of the TIROS satellite scientific measurements and provided the foundation for the advanced Nimbus missions. He led the effort that established the initial Nimbus Project as an R&D Program and then developed the relationship with Dave Johnson, who headed the ESSA Weather Bureau, to build Nimbus as their satellites in a production mode, one prototype satellite and three replicas. Stroud served as the initial Nimbus Project Manager until he became the Aeronomy and Meteorology Division

Chief, when Harry Press became the Project Manager. John Licht created the mechanical design (that turned out to be so effective in accommodating seven different Nimbus missions at reduced program costs) that was incorporated into the specification for the Nimbus build. Dr. Rudolf Stampfl designed the Nimbus electrical bus system and active thermal control system concepts, and managed the early Nimbus development activity.

**Project implementation:** William Stroud continued his important role on the Nimbus Program as the major GSFC management-level advocate of the Nimbus Program. Harry Press asserted the key role during the project implementation phases, saving the program from elimination three times as he promoted Nimbus as the meteorological research satellite program that would benefit weather forecasting and that NASA Headquarters and GSFC would be proud of. He was the primary advocate for continuing the Nimbus program after ESSA dropped out of the Nimbus-1 Observatory funding partnership with NASA. After the Nimbus-B1 disaster, Harry Press championed the funding to build Nimbus-B2 and Nimbus-C. He served as the Project Manager through the most difficult Nimbus-1 development stage, when designing for aerospace operations was still in its infancy. He was the Nimbus-1, Nimbus2, and Nimbus-3 Project Manager. His persuasive promotional efforts for the proposed future Nimbus D, E, and F missions were key to their acceptance by NASA Headquarters as new missions.

**Technical management:** Stanley Weiland served as the Integration and Test Manager for Nimbus-A, Spacecraft Manager for Nimbus-B1, B2, and C, and Project Manager for Nimbus-D, making the major technical decisions to resolve development issues, maintaining the schedules, and controlling costs. Moe Schneebaum led the large GSFC engineering Team supporting the Nimbus spacecraft and instrument development and contributing to the successful accomplishment of Observatory development. His leadership role during the early, more difficult design and development stage was outstanding. Seymour Kant served as the attitude control system engineer and the spacecraft systems engineer for all the Observatory developments, and who provided attitude control system and systems engineering support to the Nimbus Control Center for thirty years. Ralph Shapiro served as the Integration and Test Manager for Nimbus-C, managing the rapid Nimbus-C development and integration and test

effort supported only by the small Nimbus staff resident at the GE integration facility while the Project engineering Team was devoted to the Nimbus-B development effort.

**Headquarters program management:** Richard Haley, Burton Schardt, and Douglas Broome, served as the Nimbus Program Managers. Their role was to establish the mission envelope for each new mission, coordinate the selection of the proposed instruments, manage the Observatory, science program, and operations funding process, and consolidate formal arrangements required with external organizations participating in the program.

**Flight operations and data system management:** Ralph Shapiro was the Mission Operations Manager for Nimbus-1 through 7 and the overall Nimbus operations system manager for eighteen years, conducting the active, hands-on operations management. He managed the development of the Nimbus Control Center (NCC) operation plans and procedures and the complex preparation of the Nimbus Meteorological Data Handling System (MDHS) facility for the Nimbus-1 operations. He managed the flight operations software development for all seven Observatories and managed the development of the software for the MDHS data processing. He designed the Nimbus Operations Processing System (NOPS), which was the Nimbus Project facility for processing Nimbus-7 scientific data, and managed the NOPS processing for the first four years of NOPS operations. Michael Forman managed the last 12 years of Nimbus flight operations and led the significant NCC cost saving efforts that were crucial to the ability of GSFC Code 500 to fund the Nimbus and other Control Center operations.

**Science program:** Dr. William Nordberg, the first Nimbus Project Scientist, promoted the meteorological objectives and science benefits that sold the continuation of the Nimbus Project after the Project had been halted twice. His vision for future instrument capabilities and the resulting value that they would offer was vital to the acceptance of the new instrumentation proposed for Nimbus B, D, and E. His visions became a reality with the application of the data from the Nimbus instruments he advocated. Dr. William Bandeen took over as Project Scientist after the untimely death of Bill Nordberg and led the complex and productive science programs for Nimbus-4, 5 and 6. Dr. Albert Fleig, the third Nimbus Project Scientist, managed the eight Nimbus-7 Experiment Teams (NET)

efforts to standardize data products and formats, establish the science data definition process, conduct the algorithm development effort, and validate the data products.

Principal Scientists played a major role contributing to the instrument’s success by defining instrument science specifications, evaluating the vendor’s designs, calibrating the instrument, validating the data products, and conducting meaningful science research. (These activities were partially a NET responsibility for Nimbus-7.). Credits for the success of the instrument development, instrument science, and the applications of the data go to: Dr. Rudolf Hanel (IRIS), Dr. William Smith and Dr. David Wark (SIRS, ITPR), Dr. Donald Heath (MUSE, BUY, SBUV), Charles Cote (IRLS, TWERLE/RAMS), Prof. David Staelin (NEMS, SCAMS), Dr. Thomas Wilheit (ESMR), Dr. Warren Hovis (CZCS, SCMR, FWS), Prof. John Gille (LRIR), Dr. Herbert Jacobowitz (ERB), Prof. Sir John Houghton (PMR, SAMS, SCR), Dr. Per Gloersen (SMMR), Dr. Arlin Krueger (TOMS), Dr. Patrick McCormick (SAM II).

**Contractor support:** Sheldon Haas, General Electric Nimbus Program Manager, led the GE Nimbus Team in developing Nimbus-B1 that involved the integration and test of the spacecraft with all new instrumentation. He managed the rapid Nimbus-B2 recovery effort under a compressed schedule and accomplished at a low cost. He also effectively managed the Nimbus-D implementation special challenges that included the development of the improved ACS and the integration of the VIP computer telemetry system with all the spacecraft elements; all Observatory efforts were delivered within schedule

and budget. Dr. Jack Kiegler, RCA Sr. Communications Engineer, designed the complex RF multiplexer and demultiplexer systems, and served as the communications and electronic consultant to the RCA Nimbus Team and to the Nimbus Project. Bennie Palmer, the General Electric NCC Manager, set the high standard for the operations staff (e.g., responsiveness to the dynamic-mission scheduling requirements, diligence to the telemetry to protect spacecraft health, and resourceful response to Observatory aging problems). He managed the successful NCC operations for 25-years.

**Center recognition:** The annual GSFC awards program honors two major contributors to the Nimbus Project success, the late Dr. William (Bill) Nordberg and Moe Schneebaum. The Nordberg Award is granted for scientific achievement and the Schneebaum Award for engineering achievement. Dr. Nordberg, the first Nimbus Project Scientist, had the vision to see the value to meteorology of several new measurements from aerospace instruments that he proposed. This included infrared imagery for nighttime cloud cover, infrared spectrometry that inaugurated the new era of using satellite quantitative measurements of atmospheric temperature in weather forecasting models, and the application of microwave spectrum instruments to more accurately measure atmospheric temperature in the presence of clouds. Moe Schneebaum, the GSFC Engineering Directorate Chief, led the GSFC engineering team involved in the very challenging early spacecraft and instrument design and development efforts, the intensive integration and environmental test programs, and the sensitive launch phase support.

SCIENTIFIC  
INSTRUMENTATION  
OVERVIEW<sup>1</sup>

Advances in the NOAA operational satellite remote-sensing instrumentation were directly derived from the Nimbus research and development satellite Project conducted by the Goddard Space Flight Center. Starting with the first launch in August 1964, the Nimbus research satellite program of seven satellite Observatories (called Observatory by NASA because of the size of the platform and the number of instruments) with 33 different instruments operated over a 30-year period, enabling scientific study of the Earth’s meteorological and climatic behavior and deriving a comprehensive understanding of the Earth’s atmospheric, terrestrial, geological, and oceanographic characteristics and dynamic behavior. All the Nimbus instruments are listed in Table 2 along with their measurement capability and applications, and the spacecraft they flew on.

Scientific Instruments and Characteristics

There were seven successful Nimbus Observatories launched that flew 33 different, advanced meteorological and geophysical experiments covering a broad array of scientific objectives and incorporating many aerospace technological advances.

Table 3 summarizes the significant growth in the number of instruments and the dramatic changes in operating payload characteristics with each new Nimbus observatory. The satellite structural configuration readily accommodated each successive observatory payload in terms of sensor view angle requirements, instrument detector cooling requirements, instrument thermal control, and RFI constraints.

Scientific Accomplishments and Benefits  
to Mankind

The data produced by the seven Nimbus Observatories has supported a very wide array of earth science research for forty years, deepening and extending the knowledge about the sciences and raising the quest for obtaining more information to answer questions resulting from the Nimbus scientific studies. The research covers disciplines such as atmospheric science, meteorology and climatology, oceanography, cryosphere studies, solar studies, geology, cartography, agriculture, and more. The results of the individual research efforts had a major impact on the follow-on NASA, NOAA, International, and commercial satellites that supported the respective research category. The categories of research and the respective Nimbus instruments supporting this research are listed in Table 4 along with the follow-on satellites. Nimbus infrared and microwave sounders essentially served as prototype instruments for the NOAA operational Polar orbiting satellite instrumentation. The NOAA SBUV-II instruments that have been on NOAA Polar orbiting satellites since 1984 have been derived from the Nimbus SBUV instrument design. Oceanographic instrumentation on SeaWifs and the EOS family of satellites stemmed from Nimbus CZCS. TRMM and ERBE satellite instrumentation were closely patterned after Nimbus SMMR and ERB. Soviet Meteor-3 TOMS, Earth Probe TOMS, and the Japanese ADEOS TOMS all copied Nimbus TOMS. Meteor-3 TOMS used the TOMS engineering model to get off to a quick start. The Landsat program was conceived after the Nimbus AVCS high-resolution pictures, taken on a relatively stable earth-pointing Nimbus platform, demonstrated mapping capability, and the Nimbus SCMR instrument demonstrated the capability to identify surface minerals. The Nimbus platform served as the Earth Resources Technology Satellite (ERTS--initial name of

	Nimbus Observatory						
	1	2	3	4	5	6	7
Number of experiments	3	4	9	9	6	9	9
Number of spectral channels	3	8	28	43	34	62	79
Electromagnetic spectrum region							
Visible	X	X	X	X	X	X	X
Infrared	X	X	X	X	X	X	X
Far Infrared		X	X	X	X	X	X
Ultraviolet			X	X		X	X
Microwave					X	X	X

Table 3 Nimbus Observatories--electromagnetic spectrum growth of experiments.

Acronym	Instrument Name	Instrument Measurements/Application	Nimbus
APT	Automatic Picture Taking	High-resolution visible pictures, slow read-out	1,2
AVCS	Advanced Vidicon Camera System	High-resolution visible pictures; full swath coverage	1,2
BUV	Backscatter Ultraviolet Spectrometer	Atmospheric zone profile measurements	4
CZCS	Coastal Zone Color Scanner	Ocean color measurements to determine oceanic constituents; ocean temperature; ocean productivity	7
ERB	Earth Radiation Budget	Incoming and outgoing radiation measurements for earth energy balance studies	6,7
ESMR	Electrically Scanning Microwave Radiometer	Microwave spectrum radiation measurements; global sea ice concentrations, snow cover, water vapor and rainfall	5,6
FWS	Filter Wedge Spectrometer	Measure vertical distribution of water vapor and CO <sub>2</sub>	4
HIRS	High Resolution Infrared Radiometer	Full-swath atmospheric temperature profiles	6
HRIR	High-Resolution Infrared Radiometer	Day/night global cloud cover, full swath	1,2,3
IDCS	Image Dissector Camera System	Day cloud cover with slow readout capability	3,4
IRIS	Infrared Interferometer Spectrometer	Vertical profiles of temperature, water vapor, ozone, and chemical species; interferograms/spectral measurements	3,4
IRLS	Interrogation, Recording, Location System	Determines platform location, collects data	3,4
ITPR	Infrared Temperature Profile Radiometer	Atmospheric vertical temperature profiles	5
LIMS	Limb Infrared Monitoring of the Stratosphere	Views earth limb; stratospheric temperature, ozone, water vapor, nitric oxide, nitrogen dioxide	7
LRIR	Limb Radiance Inversion Radiometer	Views earth limb; temperature, ozone, and water vapor profiles from lower atmosphere to stratosphere	6
MRIR	Medium-Resolution Infrared Radiometer	Measures earth's reflected and emitted radiation	2,3
MUSE	Monitor of Ultraviolet Solar Energy	Measures solar radiation not viewed from earth	3,4
NEMS	Nimbus Experiment Microwave Spectrometer	Atmospheric temperature profiles in the presence of clouds; multi-spectral observations producing oceanic humidity and cloud water, sea-ice age, snow depth and snow accumulation rates over Antarctica.	5
PMR	Pressure Modulated Radiometer	Stratospheric temperature and chemical species	6
RMP	Rate Measuring Package	Demonstration of a gyroscope designed with air bearings	3
RTG	Radioisotope Thermoelectric Generator	Nuclear material electric power generation from nuclear material heat generation	3
SAM-II	Stratospheric Aerosol Measurement II	Map global concentrations of aerosols and optical properties in stratosphere and troposphere	7
SAMS	Stratospheric and Mesospheric Sounder	Gas concentrations and temperature profiles in the stratosphere and mesosphere	7
SBUV	Solar/ Backscatter Ultraviolet Spectrometer	Measures solar irradiance; ozone profile measurements in lower atmosphere	7
SCAMS	Scanning Microwave Spectrometer	Temperature profiles, oceanic humidity, and rain; global imagery characterizing fronts and hurricanes	6
SCMR	Surface Composition Mapping Radiometer	Earth mapping; identification of surface minerals	5
SCR	Selective Chopper Radiometer	Temperatures of six layers of the atmosphere	4,5
SIRS	Satellite Infrared Radiometer Spectrometer	Atmospheric temperature profiles	3,4
SMMR	Scanning Multi-channel Microwave Radiometer	Global sea ice concentrations and type (age) and sea surface temperatures; sea surface winds; snow cover; soil moisture; atmospheric water vapor over oceans and rainfall	7
T&DRE	Tracking and Data Relay Experiment	Data transmission from satellite to ground station thru a geosynchronous satellite; develops satellite ephemeris thru communication link range and range rate information	6
THIR	Temperature/Humidity Infrared Radiometer	Day/night global cloud cover and water vapor mapping	4,5,6,7
TOMS	Total Ozone Mapping Spectrometer	Maps total ozone in stratosphere and troposphere, SO <sub>2</sub> aerosols; volcanic ash cloud tracking	7
TWERLE /RAMS	Tropical Wind Energy Level Conversion and Reference Level Experiment/Random Access Measurement System	Equatorial wind studies; animal tracking; platform locations; data collection; RF reception of up to 200 platforms	6

**Table 2** Nimbus program total instrument complement, characteristics and satellite installation.

the Landsat satellites) spacecraft platform and the ERTS development Project was managed by Nimbus personnel who transferred to the ERTS Project.

The following research has resulted in governmental and commercial services that dramatically benefit mankind and affect our daily lives.

**Weather forecasting impact:** More accurate, longer-term (3-5 days) weather forecasting is now realistic because weather satellite systems are now capable of measuring global atmospheric and stratospheric temperature and moisture vertical profiles under clear and cloudy conditions, measuring rainfall, and collecting cloud coverage data that enables computing wind speed and direction. These quantitative measurements of the vertical distribution of temperature and moisture provided better initialization and propagation of the global numerical weather prediction models and an improved understanding of long-term climate phenomena.

**Ozone photochemistry:** In 1930 Sydney Chapman proposed that stratospheric ozone could be explained by reactions between oxygen radicals formed from UV sunlight. That basic process was confirmed by rocket ozone soundings in the 1960's. However, lab chemists knew that hydrogen, nitrogen, and chlorine species catalytically destroyed ozone. Unfortunately, the reaction rate coefficients were so poorly known that they could not rule out the Chapman chemistry. In 1972, Paul Crutzen (sinner of the 1995 Nobel Chemistry Prize) predicted that nitrogen radicals produced in that year's solar proton event would show depletion of ozone if the laboratory mechanism was correct. Donald Heath and Arlin Krueger of GSFC processed the Nimbus-4 BUV data and found the exact signature of the depletion predicted by Crutzen. That event put to rest the simple oxygen chemistry and raised questions about the effects of halogen radicals on ozone. Thus the Nimbus-4 BUV had a major role in enabling the environmental movement about the depletion of ozone from the growing industrial production of chlorofluorocarbons (CFC). The public acceptance of this theory had to wait for another transient event that appeared during the Nimbus-7 TOMS era.

Atmospheric ozone depletion and ozone hole monitoring; Scientists had been studying total ozone around the world since the 1920s using the Dobson Ozone

Spectrophotometer. This ground device measures total ozone in the upper atmosphere by looking up on a column above the instrument. Biologists had been simultaneously studying the effects of ozone depletion on human beings and on ocean productivity. In 1984 a British Research Team working in Antarctica using balloons and other ground-based equipment announced they detected polar ozone depletion. A GSFC study of images from the Nimbus Total Ozone Mapping Spectrometer (TOMS) data confirmed this degradation and revealed that there was a very large ozone hole (levels of ozone depressed below safe values) there the size of the Antarctic continent. Moreover, study of the TOMS data revealed that ozone holes had occurred there every year in the southern-hemisphere springtime. Furthermore, the long-term data showed that ozone depletion was taking place at many non-tropical locations, including the northern hemisphere. With these TOMS data revelations, the general public and the international political community became aware of the consequences of the ozone depletion in the stratosphere, i.e., the loss of protection that ozone provided against the sun's ultraviolet rays that cause skin cancer and cataracts, and the curtailment of the southern pacific fish food and CO2 ocean productivity that is so important to the world ecology balance. In 1987, seventeen countries subscribed to the Montreal Protocol, which banned CFCs thought to be the cause of the ozone degradation. The scientific community began a continuous study of ozone in the stratosphere. NASA, NOAA and the international community agreed to provide satellite data for monitoring the stratospheric ozone, i.e., 25-year continuous deployment of a TOMS instrument on NASA and international satellites, and the inclusion of the Solar Backscatter Ultraviolet Instrument (SBUV/2) on NOAA satellites. This long-term data collection program is also required to resolve how much of the ozone level variation is human induced or caused by natural changes.

**Lives saved by the Search and Rescue Satellite Aided Tracking Program (COSPAS-SARSAT):** Small boat and general aviation single engine aircraft accidents occur routinely throughout the world. It is estimated that approximately 300 lives are saved annually through their rapid location and rescue facilitated by the 38-nation international COSPAS-SARSAT system that evolved from the Nimbus-6 TWERLE experiment with its RAMS component, and the French ARGOS Data Collection System, which enabled reception and location from 200 platforms

within the satellite field of view. TWERLE demonstrated this capability, locating two balloonists trying to cross the Atlantic, who were downed in a storm and lost in the North Atlantic out of sight of rescuers. The experimental TWERLE platform that they carried transmitted a signal through the Nimbus satellite to the Nimbus Control Center where their location was calculated within the next hour, leading to their rescue. TWERLE was also instrumental in the tracking of a Japanese adventurer while crossing Greenland solo on a dogsled. An emergency transmission code was available if needed, and was successfully tested, although a real emergency did not occur. The satellite derived locations were also used to direct a small aircraft to the dogsled for the delivery of supplies. Based on these experiences, GSFC engineers with experience working with the TWERLE system and its predecessor IRLS system, that also had a remote platform location capability, promoted the concept for the SARSAT Program which was eventually developed by France (CNES) and flown on NOAA satellites. It would conduct search and rescue operations based on the TWERLE/RAMS system technology. SARSAT operational search and rescue system that necessitated uses rescue aircraft with the right equipment to be in the vicinity of the downed aircraft for locating the aircraft from the plane's Emergency Locator Transmitter (ELT).

**Atlantic hurricane and Pacific cyclone watch:** Atlantic hurricanes, a yearly occurrence, can be devastating to human lives and property. Nimbus-1 daylight visible and nighttime infrared pictures of intense hurricane clouds viewed from space initiated the use of satellite technology to provide warnings to protect against hurricanes, saving many lives. Starting with Nimbus-1, which captured a picture of a typhoon otherwise unreported, typhoons in the vast Pacific Ocean no longer go unrecognized because they are now observed and monitored by satellite. In addition, microwave sounding instruments initiated by the Nimbus Program now provide capabilities to analyze hurricane intensity.

**Volcanic eruptions and aviation hazards:** Explosive volcanic eruptions are responsible for great destruction on the ground and, since the advent of jet aircraft, have disabled passenger jets while in flight. The eruption clouds are generally too large to measure from the ground or from aircraft. The Nimbus-7 TOMS fortuitously could measure a unique tracer of eruptions, sulfur dioxide as well as

volcanic ash, thus providing the first quantitative data on the size of these eruptions. Data from every eruption since 1978 have led to a completely new understanding of eruption processes. We now know that eruptions are powered by gases that separate from the magma over decades and provide a path to the surface. In addition, maps of the drifting volcanic clouds provide the first accurate information for diverting aircraft from this hazard. Experimental Nimbus TOMS real-time and near real-time data processing capabilities were developed to provide locations of these clouds, enabling the rerouting of commercial aircraft to avoid these dangers. NOAA and USGS now utilize this TOMS methodology for operational hazard warnings.

**Aircraft flight optimization:** The GSFC scientists analyzing TOMS data, led by Dr. Arlin Krueger, found a relationship between TOMS total ozone gradients and jet stream winds at the high altitudes flown by aircraft across the United States. In addition, cabin ozone was a concern before filters were installed. They developed the algorithm to rapidly process the raw TOMS data after it was received at the Nimbus Control Center (within a half-hour after the data was taken) to identify the winds altitude and locations. The Nimbus Operations Team at GSFC operated this experimental system, processing the data and sending it in near-real time to the Northwest Airlines, who joined GSFC to develop this experimental system.

*Technology Transfer*

The Earth's resources can now be better managed through use of satellite terrestrial and oceanographic data to assess land vegetation growth, determine tropical deforestation, map snow and sea-ice cover, determine ocean and maritime qualities, and create accurate maps. Important land resource and environmental data from thousands of sensors on unattended remote platforms can now be automatically collected through satellites. Animal and fish migration can be studied by attaching collars that communicate with satellites. Ship routing in the Arctic is facilitated using satellite microwave instrument data that distinguishes clear shipping channels from the pack ice. Commercial fisherman can locate schools of tuna from satellite ocean-color measuring instruments. GSFC scientists and other national and international research organization scientists initially demonstrated all of these capabilities through their analysis of the data from the 33 different Nimbus experiments on the seven Observatories, collected over a thirty-year period. The broad scope of the GSFC

Research Study Category/Application	Nimbus Instrument	Follow-on GSFC Satellite Programs and Other Satellite Programs
Atmospheric moisture	SCAMS,	Aqua, NOAA satellites, DoD, International satellites
Atmospheric ozone	BUV, SBUV	NOAA satellites
Atmospheric chemistry	IRIS, LIMS, SAMS, SCR	UARS, Aura, Voyager, Cassini
Atmospheric temperature	IRIS, SIRS, HIRS, PMR, NEMS, SCAMS	Voyager, Cassini, Aqua, Terra, NOAA, DoD and International satellites
Climatology	MRIR, ERB, SAMS, LIMS, SMMR, HIRS, PMR, NEMS	ERBE, Aqua, Terra, NOAA satellites
Cloud cover study	AVCS, APT, IDCS	ICESat, Terra, NOAA satellites
Cryosphere (polar ice)	ESMR, SMMR	Aqua, Terra, ICESat, NOAA satellites
Data collection from oceanic and hydrologic platforms; fish and animal tracking	IRLS, TWERLE	NOAA satellites, International satellites
Day/night cloud mapping	HRIR, THIR	Terra, NOAA satellites
Geology	SCMR	ERTS, Landsat, HCMM
Hurricane study	AVCS, APT, IDCS, SCAMS, NEMS, THIR, HRIR	NOAA satellites, International satellites
Ice fields and snow cover	SMMR, ESMR	ICESat, Aqua, Terra
Mapping	AVCS, ESMR	ERTS, Landsat, ICESat, Terra
Meteorology	SIRS, HIRS, PMR, NEMS, SCAMS	Aqua, Terra, NOAA satellites, International satellites
Mineral resources	SCAMS	Landsat
Ocean productivity: chlorophyll, phytoplankton, phytoplankton, CO <sub>2</sub>	CZCS	SeaWifs, Topex/Poseidon, Aqua, Terra
Oceanic pollution	CZCS	SeaWifs, Topex/Poseidon, Aqua, Terra
Rainfall, water vapor	ESMR, SMMR, SCAMS, NEMS	TRMM
Satellite ephemeris	T&DRE	Future satellites communicating through TDRSS
Sea ice concentrations	SMMR	SeaWifs
Sea surface temperature	CZCS, SMMR	SeaWifs, Topex/Poseidon, Aqua, Terra
Soil moisture	SMMR	Landsat, Aqua
Solar radiation	MUSE, S/BUV, ERB	UARS, Solar observatories
Stratospheric aerosols	TOMS, SAM-II	SAGE, TOMS on Soviet Meteor-3, TOMS-EP, Aqua
Stratospheric chemistry	PMR, SAMS, LIMS, LRIR	UARS, Aura
Stratospheric ozone	TOMS, LRIR, BUV, SBUV	TOMS on Soviet Meteor-3,TOMS-EP, SBUV/2 on NOAA satellites; ADEOS TOMS
Surface wind above ocean	SMMR	TRMM, SeaWifs, Topex/Poseidon, Aqua
Vegetation and forestry	AVCS, SCMR	ERTS, Landsat, Terra
Volcanology, volcanic ash cloud tracking	TOMS	Meteor-3 TOMS, ADEOS TOMS, TOMS-EP, OMI, OMPS

**Table 4 Nimbus data supported a wide variety of scientific discipline research.**

and other community scientific research studies and of the resultant services now available that are attributable to the Nimbus Program is indicated in Tables 4 and 5.

Several technologies were included in the Nimbus program. They are listed in Table 6. The Radioisotope Thermonuclear Generator (RTG) demonstration paved the way for RTG power generation on deep-space satellites to the outer planets. The TWERLE/RAMS system was the genesis of the international SARSAT program and the NOAA remote platform data collection and location network.

Many national and international earth-observing satellite programs evolved over the past twenty years that were extensions of the Nimbus satellite remote-sensing technology program (Tables 4 and 5). The scientific research applied to the data from these satellites is dedicated to the continued and better understanding the planet Earth's behavior. NASA/GSFC has been in the forefront of this continuing United States role in Earth remote sensing and related scientific research activities. The tables also indicate the Nimbus heritage of the many GSFC and other institutional follow-on satellite programs. The latest NASA/

GSFC major program, the Earth Observing System (EOS), has placed three Observatories in orbit since December 1999, Terra for studying the Earth's environment and ongoing changes in its climate system, Aqua, for studying oceanographic and moisture related properties, and Aura, launched this summer, concentrating on the composition and dynamics of the Earth's atmospheric chemistry. Most of the EOS Program scientific measurement requirements that were defined in 1984/85 to initiate the EOS Program were intended to address questions about the Earth's land, ocean, and atmospheric composition and behavior stemming from the Nimbus data scientific research.

The capabilities described are being expanded through the continuing Earth science research being conducted by NASA scientists and other research organizations applying newly collected satellite data.

The Nimbus instrument technology was also transferred to NASA satellites. The heritage of instruments on most Earth-resources satellites launched over the past three decades can be traced to Nimbus instrument technology and/or scientific accomplishments.

Application	Instrument	Organization Supported/Technology Transfer
Ozone/jet stream measurements for aircraft routing support	TOMS	Northwest Airlines, TOMS/EP
Commercial tuna fishing	CZCS	Commercial fisheries; Scripps Institute, SeaWife
Spacecraft gyroscopes	RMP	Gas-bearing gyroscopes on satellites
Hurricane tracking	AVCS, APT, IDCS, SCAMS NEMS, HRIR, THIR	NOAA satellites, International satellites
Oil spill monitoring	CZCS	Oil companies; ERTS, Landsat, SeaWifs
Remote platform data collection	IRLS, TWERLE	NOAA services and NOAA satellites, French satellites
Satellite electric power source	RTG	JPL deep space satellites
Downed aircraft and ship search and rescue	TWERLE/RAMS	SARSAT NOAA satellites, Soviet/Russian satellites
Ship routing thru Arctic ice fields	ESMR, SMMR	Joint NOAA/Navy Ice Center
Stratospheric ozone analysis for ozone hole detection	TOMS, LRIR, BUV, SBUV	TOMS on Soviet Meteor-3, TOMS-EP, NOAA satellites
Volcanic ash cloud monitoring for aircraft re-routing	TOMS	Commercial aircraft, SAGE, TOMS on Soviet Meteor-3, TOMS-EP
Weather forecasting	SIRS, HIRS, PMR, SCAMS, NEMS	National Weather Service, NOAA satellites, International satellites

Table 5 Nimbus provided a wide variety of beneficial services to the public.

Instrument Name (acronym)	Instrument Measurements/Characteristics	Nimbus
Interrogation, Recording, Location System (IRLS)	Interrogates and receives platform RF signal and collects platform doppler information to enable locating platform; collects platform data	3,4
Rate Measuring Package (RMP)	Demonstration of a gyroscope designed with air bearings; used in later gyroscope space applications.	3
Radioisotope Thermoelectric Generator (RTG)	Experimental nuclear electric power generation	3
Tracking and Data Relay Experiment (T&DRE)	Demonstration of the upcoming TDRSS data transmission from satellite to a ground station thru a geo-synchronous satellite; develop satellite ephemeris thru range and range rate communication information	6
Tropical Wind Energy Level Conversion and Reference Level/Random Access Measurement System (TWERLE/RAMS)	Remote platform data collection; same capability as IRLS on Nimbus-3, -4 without the need to interrogate the platform	6

Table 6 Technological instrument characteristics and satellite installation.

NIMBUS-1 OVERVIEW  
08/28/1964 – 09/23/1964

Nimbus-1, the first civilian 3-axis earth-pointing satellite, was stabilized within one degree. This arrangement was very effective for the 1-inch, 800-line resolution, 0.5-7.5um, Advanced Vidicon Camera System (AVCS) that provided high quality cloud pictures that could be taken around the world and recorded for playback on a wideband tape recorder (new technology for space application). Three side-by-side vidicons covered the full 2300-Km swath width. This gave the U.S. Weather Bureau an improved capability to study weather phenomena outside of the United States that influenced the weather over the United States. On the third day, this camera system provided an exceptional clear picture of Hurricane Cleo, and subsequently tracked another hurricane and a Pacific typhoon. In addition, the AVCS pictures enabled cartographers to correct inaccuracies on relief maps and supplied better definition of the Antarctic ice fronts. Nimbus went into the first of its several semi-operational modes during the program lifetime; scheduling of the limited AVCS cloud picture recording capability was coordinated with a Weather Bureau operational representative to cover weather features of timely interest to the Weather Bureau. A rapid-processing system, developed by the Photomechanisms Corp, generated the pictures in the Nimbus ground station at GSFC from the AVCS electrical picture data.

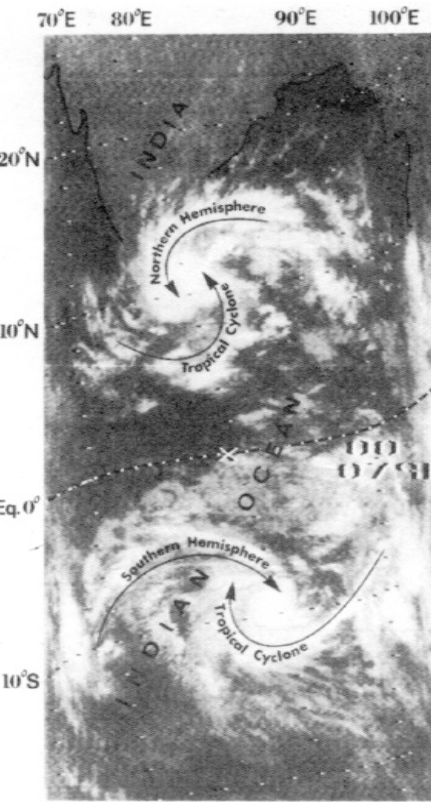
Another major success was the Automatic Picture Taking (APT) system. This instrument used a 1-inch, 0.5-7.5um, 800-line resolution, stored image vidicon with a slow readout capability that was compatible with the commercial facsimile image recorders available for displaying the pictures received at local weather stations. (It had flown earlier on a TIROS satellite, but the local area coverage was not systematic.) The local cloud pictures that covered approximately 1,500 miles thrilled the world meteorological community. They could receive this weather data from this high-resolution camera system at about the same time daily by using a small inexpensive antenna/receiver and a facsimile recorder. The Nimbus Project sponsored the development of an inexpensive integrated APT receiving/display system by the Fairchild Camera Corp, to be ready before the launch of Nimbus-1. This APT system became the source of local cloud pictures displayed on the TV

news channels that became a routine TV feature for many years. By the launch of the next Nimbus satellite, which also contained an APT camera system, the number of APT stations had grown to over 300, located in 43 countries.

The third instrument was the High-Resolution Infrared Radiometer (HRIR) that operated in the 3.4-4.2um spectral interval with a rotating mirror for scanning horizon to horizon. It provided the first nighttime cloud pictures from space, a boon to the meteorologists. It provided global daytime and nighttime cloud coverage. A facsimile recorder that produced high-resolution negatives from the electrical data signals was developed the Westrex Corporation. Daily mosaics of worldwide clouds were produced for global cloud behavior and related weather analysis.

Nimbus-1 failed after 28 days due to the seizure of the solar array drive motor. The array designers overlooked the absence of convection in the airless space environment when they selected a small commercial motor for the array drive speed-reduction mechanism early in the Nimbus development program. The rotor was bright-colored instead of radiative-black, and could not radiate sufficiently to compensate for the lack of convective rotor cooling in the operational vacuum environment. The rotor heat could only be dissipated through the motor's small half-

inch ball bearing, causing the bearing grease lubricant to dry out.



Twin tropical storms on the same day taken by HRIR.

**NIMBUS-2 OVERVIEW**  
**05/15/1966 – 01/18/1969**

Nimbus-2 was authorized along with the Headquarters authorization of the developmental Nimbus-3 Observatory that included the next generation of meteorological experiments. Nimbus-2 was approved as a copy of the Nimbus-1 configuration, with the addition of an available instrument, that could be built rapidly at a relatively low cost. The objective was to provide a continuation of the Nimbus-1 application benefits to the meteorological community and provide data to support the scientific research initiated by Nimbus-1 until the next Nimbus with more advanced instrumentation was to be available. Nimbus-2 operated for thirty-two months.

Nimbus-2 contained four instruments: three identical to the Nimbus-1 complement (APT, AVCS, and HRIR) and one additional instrument, the Medium-Resolution Infrared Radiometer (MRIR). It was produced using a spacecraft structure residual from the original Nimbus Project plan to build three identical spacecraft, and required the incorporation of RF isolators to avoid RF interference with the addition of the new MRIR data stream to be included in the VHF communication link.

Continuing the Nimbus-1 experience, the APT pictures were exploited by the worldwide local forecasters and TV stations. The capability of transmitting local nighttime cloud pictures from the HRIR instrument was added to the real-time transmission system capability. This feature provided a nighttime view of local cloud conditions and other benefits such as temperature patterns of lakes and oceanic areas of interest to shipping and fishing industries. The high- resolution AVCS pictures that gave insights to storm patterns were of continued interest to the research community.

The new instrument, Medium-Resolution Infrared Radiometer (MRIR), measured radiation emitted and reflected from the Earth in five wavelength intervals from visible to infrared (0.5-29um). MRIR data was used to study the effect of water vapor on the Earth's energy balance.

**NIMBUS-3 OVERVIEW**  
**4/14/1969 – 1/22/1972**

The Nimbus-3 Observatory was the first of the line of Nimbus spacecraft with experimental meteorological and other science instrumentation built under the renewed Nimbus charter as a research satellite program. Nimbus-3 operated for 32 months.

Nimbus-3 carried nine experiments compared to three for Nimbus-1, covering 28 spectral channels compared to 3 for Nimbus-1. Seven experiments, including three that were completely new, were scientific and two were technology. One new experiment provided a breakthrough on the weather prediction modeling techniques that resulted in improved forecasting accuracy. Another new experiment was the forerunner of satellite search and rescue technology by demonstrating satellite collection of remote platform data and the capability to locate remote platforms. Another new experiment served as the forerunner of the instruments that measured the temperature and chemical composition of the outer planets using infrared interferometer technology.

The Satellite Infrared Spectrometer (SIRS) instrument on Nimbus-3 inaugurated a new era in weather forecasting by the use of satellite instrumentation to make the meteorological measurements required for weather forecasting. It was a grating spectrometer with 8 channels in the 11-15um spectral interval which pointed to the nadir with a 12-degree angular field of view. Nimbus SIRS data provided the first daily measurements of atmospheric temperature profiles suitable for numerical weather prediction that covered the globe. The new SIRS data presented a major challenge to the meteorological community. They needed to develop techniques of converting the raw radiance measurements to temperature profiles and develop robust global numerical weather prediction models that could absorb and integrate this new type of information. This high volume of global data replaced the relatively sparse radiosonde and rawinsonde temperature and wind data essentially collected by U.S. weather forecasters only over the United States and by a few ships at sea. SIRS data was delivered to NOAA/NESDIS in near real-time in a pseudo-operational mode for two years. This cooperative routine enabled NOAA to develop the raw data temperature inversion algorithms, to develop the techniques

for integrating the large volume of computed data into their weather forecast models, and to refine the forecast models. These algorithms and processes were adapted to handle data from the upcoming NOAA satellite carrying the operational Infrared Temperature Profile Radiometer (ITPR) instrument that was patterned after SIRS.

The Interrogation, Recording, and Location System (IRLS) demonstrated the feasibility of using polar orbiting satellites to locate and collect data from remote instrumented platforms around the globe. Environmental data was collected from balloons and buoys for wind studies and ocean current studies. Animal and large fish migration was studied using signals received by IRLS from transmitters attached to the animals and fish to compute their locations at the Nimbus Control Center. It was necessary for commands to be sent to IRLS to interrogate the platform before the platform would activate to send its data. The computation of the platform location was performed for the experimenters by a computer program developed by the Nimbus Project and operated in the Nimbus ground system in Building 3 at GSFC.

The Infrared Interferometer Spectrometer (IRIS) instrument was a modified version of the classical Michelson Interferometer. It was nadir looking, covered the 5-25um spectral interval, and had a built-in self-calibrator. The interferograms created by IRIS on the spacecraft were converted on the ground to thermal emission spectra. This data yielded vertical profiles of temperature, water vapor, and ozone, and other chemical species. Another IRIS flew on Nimbus-4. Other versions of interferometers based on the successful Nimbus IRIS design flew on the Voyager spacecraft to Jupiter, Saturn, Uranus, and Neptune, and on the MARS Mariner 9 mission and the Cassini mission to the outer planets. They measured the planet's atmospheric temperature, determined the elements or compounds in the atmosphere, and multi-spectral reflectance. All versions of this spectacular instrument were managed by the Nimbus IRIS Principal Scientist, Dr. Rudolf (Rudy) Hanel.

The Monitor of Ultraviolet Solar Energy (MUSE) experiment measured solar radiation previously undetectable at the Earth's surface because of the atmosphere's screening effect. The primary objective was to look for changes with time in the ultraviolet solar flux in five broad bands in the 1120-3100Å range. MUSE looked at the setting sun

as the spacecraft crossed the terminator in the Northern Hemisphere. It discovered that there is a pronounced periodic variation in solar ultraviolet radiation that corresponds to the 27-day solar rotation period that could affect upper atmosphere ozone concentrations.

The Image Dissector Camera System (IDCS), which demonstrated the new electrically scanned imaging radiometer technology for space applications, replaced the AVCS visible sensor. It took 800-line resolution daytime cloud-cover pictures that were stored on the high data rate recorder for playback at the tracking and data acquisition sites. It also replaced the APT system; it had a slow scan readout mode for the APT-type real-time data transmission system. The IDCS frame covered approximately 2500 kilometers on each side with a pixel resolution of 4Km.

Two technological experiments flew successfully on Nimbus-3, the Radioisotope Thermoelectric Generator (RTG), and the Rate Measuring Package (RMP). The RTG demonstrated a nuclear electric power generation capability designed for operating in space. The RTG design was later adapted for several deep space missions going beyond the reach of sunlight. The RMP was an experimental gyroscope, pressurized to support an air bearing design that would result in lower gyro signal noise and extended longevity. It demonstrated the efficacy of a gas-bearing gyroscope that later became a standard design for space applications.

HRIR, with a 0.7-1.3um channel added, and a copy of the Nimbus-2 MRIR instrument completed the instrument complement.

## NIMBUS-4 OVERVIEW

### 04/08/1970 – 09/30/1980

Nimbus-4 carried nine instruments and incorporated two major spacecraft improvements ((the Versatile Information Processor (VIP) and an improved attitude control system.)) Two were new instruments, the Backscatter Ultraviolet Spectrometer (BUV) and the Selective Chopper Radiometer (SCR). They were breakthroughs in providing knowledge of the Earth's upper atmosphere. Six instruments that were repeats or improvements of instruments previously on Nimbus-3 in order to continue the scientific research (IDCS, IRIS, IRLS, MUSE, SIRS, THIR), and one new instrument, the Filter Wedge Spectrometer (FWS), which never operated successfully. Nimbus-4 operated for 10 years.

The Backscatter Ultraviolet Spectrometer (BUV) experiment was a 12-channel grating monochromator spectrometer in the 2500-3398Å range, capable of measuring earth radiance to six orders of magnitude. BUV initiated our understanding of ozone patterns in the atmosphere. It operated for ten years, providing data that showed time-changing ozone profiles that varied around the world. The unanswered questions that came out of the BUV data analysis and the area coverage limitations provided the basis for later flying the Nimbus SBUV profiling instrument and the Total Ozone Mapping Spectrometer (TOMS) instrument on Nimbus-7 that measured the global total ozone rather than the single-point ozone profiles measured by BUV. BUV is the instrument with the most continuous use in satellite applications. It was flown again on Nimbus-7 in 1978, and has been on NOAA satellites continuously since 1984.

The Selective Chopper Radiometer (SCR) experiment was developed jointly by the UK Oxford and Reading Universities under the leadership of Sir John Houghton. It determined the temperatures of six successive 10-km layers of the atmosphere from absorption measurements in the CO<sub>2</sub> band from 2 to 200um, which yielded an innovative and meteorological-beneficial set of data. In measuring the stratospheric temperature, it was discovered that there were sudden warmings of the winter stratosphere near the North Pole that adversely affected global climate. Monitoring stratospheric temperatures became new data points of interest to the meteorological community for weather forecasting.

The Filter Wedge Spectrometer (FWS), intended to measure the vertical distribution of water vapor and carbon dioxide, was the first instrument with a detector that was radiatively cooled by looking at deep space. It failed due to icing that built up on the detector after launch that could not be removed. It provided a lesson learned to other instrument designers. Because of its failure, all future instrument radiative coolers were designed with either a cooler door and/or heaters to evaporate any frozen condensation on the detector or cooler interior as the spacecraft entered deep space after launch and before the instrument activation. In addition it became standard practice to allow a lengthy period of time for the cooler chamber to outgas before activation.

The SIRS instrument was modified to scan 35° across the swath and 6 channels were added, which greatly enhanced the meteorological forecast models.

The THIR instrument, which replaced the HRIR instrument that flew on Nimbus 1-3, had a 6.7um water vapor channel and a 10-12um long-wave channel. The former, designed to show moisture distribution in the stratosphere and upper troposphere, provided vivid portrayals of jet streams and large storm systems. The 10-12um channel, where there is virtually no sunlight, eliminated glint problems often seen in the HRIR data, and provided pictures of unusual clarity and contrast.

The Versatile Information Processor (VIP) was a state-of-the-art computer processor designed to operate in space. It was designed to handle all spacecraft telemetry and the low rate instrument science data with a 4kbps data rate. It had precision sample and hold circuitry for digitizing the input analogue telemetry and had the capability to be reprogrammed to change the sampling rate of the input telemetry and reprogrammed from the ground to provide this capability to change telemetry sampling rates to aid in diagnosing in-flight problems. It proved invaluable in being able to accommodate the integration of the data from new complements of low rate instruments on Nimbus 5-7 with a small software effort, which was a significant cost saving to the program.

The Attitude Control System (ACS) system was modified to include improvements that provided greater stability and more accurate attitude information to improve the quality of the science data, and provided improved ACS

and spacecraft reliability. The changes included a finer sun sensor for improved azimuth attitude determination and a set of magnetic torquer bars for backup momentum control, which proved to be an asset for extending the life of the spacecraft. Spacecraft ran well beyond their design life and the ACS momentum control system’s pneumatic

capacity limitation would have curtailed the spacecraft lifetime. This system was used for all spacecraft as they aged, starting with Nimbus-4. Nimbus-7 operated for 15 years with the magnetic torquer bar system for momentum unloading was used exclusively for the last seven years of operation.

## NIMBUS-5 OVERVIEW

### 12/04/1972 – 03/29/1983

Nimbus-5 carried just six instruments. Two instruments, the Nimbus Experiment Microwave Spectrometer (NEMS) and the Electrically Scanning Microwave Radiometer (ESMR), introduced a new realm of technology to satellite remote sensing, the use of the microwave frequency spectrum. A third instrument, the Surface Composition Mapping Radiometer (SCMR), expanded the Nimbus experimental program into terrestrial research. A fourth instrument, the Infrared Temperature Profile Radiometer (ITPR), was an improvement on the predecessor SIRS atmospheric sounding instrument. A fifth instrument, the Selective Chopper Radiometer (SCR) was also an improvement of an earlier instrument. THIR was the sixth instrument. Nimbus-5 operated for a little over 10 years. Nimbus-5 was turned off to eliminate competition with Nimbus-7 for data acquisition site coverage. It had marginal science utility at that time and was being operated to provide spacecraft-longevity engineering data.

The Nimbus Experiment Microwave Spectrometer (NEMS) was the first microwave sounding device. It was a Dicke superheterodyne microwave radiometer, operating with 5 channels between 20-60GHz with a 10° beamwidth. It had the capability to probe through dense clouds to provide atmospheric temperature profiles. NEMS was the first to provide multispectral measurements that separated humidity and cloud water contributions. It was also the first to provide extensive global observations of ice microwave spectral signatures, indicating sea-ice age, and snow depth and snow accumulation rates over Antarctica. NEMS was the forerunner of the Advanced Microwave Sounder Unit (AMSU) on the NOAA operational satellites.

The Electrically Scanning Microwave Radiometer (ESMR) was the first microwave device to map global radiation from the Earth’s surface and atmosphere. It had an electronically scanning Dicke-switched phased array antenna (74°), operating at 19.35 GHz with a beamwidth of 1.1°. ESMR had the capability to distinguish rain over the oceans and between snow and ice. The latter capability revealed errors in ice canopy maps and enabled clear shipping channels in the Arctic ice fields to be identified. An operational arrangement was set up to deliver ESMR ice field pictures generated at the MDHS to the Joint NOAA/

Navy Ice Center in Suitland, MD for their operational use in routing ships through the Arctic ice-free sea channels.

The third instrument new instrument was the Surface Composition Mapping Radiometer (SCMR). This imaging radiometer/spectrometer introduced the technology of mapping the Earth’s mineral resources from space. The SCMR technology and evolved into the Multispectral Scanner System (MSS) instrument on the Landsat satellites that made similar measurements with far greater resolution and accuracy. SCMR had 3 data channels (0.8-1.1um, 8.3-9.2um, 10.5-11.3um), and scanned horizon to horizon (86°) with an angular resolution of .75°.

The Infrared Temperature Profile Radiometer (ITPR), had an expanded spectral interval compared with the Nimbus-4 SIRS instrument that it was patterned after, i.e., 3.8-15um vs. 11-15um, a field of view sharpened to 1.5 degrees, double the number of sensors, and double the Nimbus-4 SIRS scanning range (76° vs. 35°). ITPR was operative until shortly before Nimbus-5 was shut down.

THIR was carried as the sixth instrument to provide a global cloud reference for the other instrument data.

Nimbus-5 presented an opportunity to learn about the ACS earth acquisition and stabilization capability. In its eighth year of operation, the combination of solar array degradation and orbit drift out of the sun plane reduced the array output to marginally support the operating power load. A sudden loss of a small array string was enough to upset the power balance and the cumulative negative power balance caused an under-voltage of the voltage regulator sufficient to shut it down. A plan to try to re-activate the spacecraft was developed, consisting of the Alaska tracking site, when in daylight, routinely repeatedly sending a command sequence that would put the spacecraft in the absolute minimum spacecraft condition, including turning the THIR motor off. The perseverance paid off. After about three months, the spacecraft beacon reappeared. Although the spacecraft had gone into a tumbling mode, the solar array orientation became aligned to the sun sufficiently long enough to activate the voltage regulator accept the commands, and the ACS reacquired the Earth’s horizon and stabilized. There were no new failures and the THIR motor ran normally after being turned back on. The spacecraft operated with ITPR and THIR for approximately another year before the spacecraft was turned off.

**NIMBUS-6 OVERVIEW**  
**03/12/1975 – 03/29/1983**

Nimbus-6 had a profound effect on meteorology akin to the Nimbus-3 impact. The type and quality of measurements taken by three of its instruments enhanced the robustness and sensitivity of the worldwide meteorological forecast models, extending weather prediction accuracy to 3 days and beyond. It had 9 experiments with a total of 62 spectral channels. Nimbus-6 operated for 8 years. Nimbus-6 was turned off to eliminate competition with Nimbus-7 for data acquisition site coverage at the time when Nimbus-7 was operating at is peak.

The High Resolution Infrared Spectrometer (HIRS) was a high-resolution temperature sounder based on the SIRS temperature sounder technology. It had additional channels (17 total) selected to cover the depth of the atmosphere (0.7-15um), and scanned 72° to cover the breadth of the orbital swath.

The Scanning Microwave Spectrometer (SCAMS) produced temperature profiles, oceanic humidity, and rain. SCAMS produced the first global microwave imagery characterizing fronts, and hurricanes. It was the first to reveal a hot spot near the eye of a hurricane and the first to be a good indicator of hurricane wind strength. It was a mechanically scanning radiometer, with 5 channels operating in the 20-60GHZ range, having a 7.5° beamwidth, and scanning 86°.

The Pressure Modulated Radiometer (PMR), developed by Oxford University, UK, was an advanced design of the earlier SCR instrument that measured stratospheric temperature (up to 85Km altitude) and chemical species. Data from PMR was routinely delivered in near-real-time to the British Meteorological Service for their operational use. PMR had 2 channels operating at 15um that scanned 15°.

Data from these three instruments was routinely provided to NOAA for developing algorithms for deriving their meteorological data and for modifying their forecast models in anticipation of the future NOAA satellites that would generate the equivalent data. The positive impact these three instrument data sets had on weather forecast models was demonstrated during the yearlong First GARP

Global Experiment (FGGE) in 1978 that was conducted by the major national and international meteorological modeling centers. The Nimbus-6 data contributed to more accurate 5-day forecasts compared to the other data sets that were tried. The types of measurements made by these three Nimbus instruments were incorporated into the TIROS Operational Vertical Sounder (TOVS), which has become NOAA's standard operational atmospheric measuring system for their polar orbiting satellites. TOVS consists of three elements, HIRS/2 (High Resolution Infrared Spectrometer/2), SSU (Stratospheric Sounding Unit), and MSU (Microwave Sounding Unit). NOAA developed their algorithms for deriving the meteorological products from these instrument data by using the equivalent Nimbus data.

Another Nimbus-6 experiment, Tropical Wind Energy Conversion and Reference Level (TWERLE), had a profound impact on the search and rescue methodology used worldwide. The basic instrument research objective was to measure winds by locating platforms attached to balloons that circumnavigated the globe near the equator. Ocean currents and ice movements were also to be measured by the same technique. During the first year of operation, 31 investigators representing seven countries had activated over 700 platforms. The TWERLE design eliminated the need for the platform to interrogate the spacecraft that was required by the predecessor Nimbus-4 IRLS location system. TWERLE/RAMS had the ability to randomly access signals from 200 platforms within the Nimbus field of view. These features proved excellent for small aircraft and boat search and rescue purposes. TWERLE first became prominent in this regard with the rescue of the two balloonists, Ben Abruzzo and Max Anderson, trying to cross the Atlantic in their Double Eagle balloon in 1977. The TWERLE platform (served as a ground communication terminal) that they decided to carry enabled the Nimbus Control Center to locate them after their balloon was downed by a violent storm off Newfoundland and they were lost at sea because there was no airplane tracking them on this mission. This rescue was followed by an experiment with Japanese polar adventurer Naomi Uemera on his first attempt to dogsled solo across Greenland. He carried a TWERLE platform that contained an emergency code to be used in the event of an emergency. The code was successfully tested although a true emergency did not occur. These life-saving experiments were preceded by British aviatrix Sheila Scott, who carried a Nimbus-4 IRLS

platform (which included a distress signal feature) on her attempt to be the first person to solo fly a light aircraft across the North Pole and then around the world. The Nimbus Control Center tracked the flight for her safety (her safety responsibility was officially assigned to the U.S. Navy) by computing the IRLS ILRS platform locations, thereby confirming that her plane crossed the Pole. These successful life-saving efforts led GSFC to promote the use of the TWERLE location technique in a satellite search and rescue program (SARSAT). It has become an international satellite program called COSPAS-SARSAT, now in place for twenty years using Russian and U.S. satellites respectively to locating downed aircraft and ships in distress, and credited with saving hundreds of lives annually. Another TWERLE feature of automatically collecting environmental data from unattended remote platforms was broadly demonstrated through environmental platform data collection and animal tracking exercises.. This capability evolved into a French satellite data collection system called ARGOS that was later replaced by what became a standard NOAA satellite operational capability for global U.S. data collection and location determination requirements.

The Limb Radiance Inversion Radiometer (LRIR) experiment had an unconventional remote sensing method of viewing the atmosphere. By viewing the limb of the earth (10° in .2° slices) it was able to see the layers of the atmosphere directly as opposed to the normal method of looking down at the top of the atmosphere and inferring the altitude from the measurement characteristics. LRIR measured temperature, water vapor, and ozone in 10-km slices from above the Earth to space. The design demonstrated the capability of low temperature detectors to handle very low radiation signal levels; the detector was cooled to 63° K by a two-stage solid-cryogen cooler. The cryogen requirement gave the instrument a nominal 6-month lifetime, which it achieved. This instrument was followed by the Limb Monitoring of the Stratosphere (LIMS) on Nimbus-7, which also required a cryogen-cooled detector because of the low signal levels viewing a small section of the Earth's limb.

The Earth Radiation Budget (ERB) experiment initiated the comprehensive scientific study of the balance between the solar incoming radiation and the Earth's outgoing radiation, essential to understanding climate changes. This research was continued with the Nimbus-7 ERB

instrument and expanded later with two ERBE satellites carrying a suite of similar instruments dedicated to studying the Earth's radiation balance. ERB measured short-wave radiation from 0.2-5 um, longwave radiation from 5-50um, and total radiation from 0.2-50um. It measured solar radiation between 2000 Å and 50um. It had a total of 22 scanning and non-scan channels.

The ESMR instrument was included on Nimbus-6 to continue producing quality global microwave data generated previously produced by the Nimbus-5 ESMR for supporting long-term cryosphere ice formation, land snow cover, and rainfall analysis. This ESMR had 2 channels that operated at 37GHz.

The THIR instrument was included to provide daily global cloud images that served as a meteorological background reference for the other experiment data.

The Tracking and Data Relay Experiment (T&DRE) was a technology experiment to demonstrate the technique for a low earth orbiting spacecraft to transmit data to the ground via the Tracking and Data Relay System (TDRS) geosynchronous satellite that was going into operation at a later date. Another purpose of the experiment was to gain information on the use of such a link for range and range rate communications for satellite geodetic purposes. This experiment provided the Nimbus portion of a communication link from the Nimbus spacecraft to the data acquisition site to the NCC through ATS-6.

NIMBUS-7 OVERVIEW
10/24/78 – 02/14/1995

The objectives of the Nimbus-7 mission represented a new an ambitious challenge. In addition to the development of instrument sensors to measure atmospheric and oceanographic features never measured before from space, the program goal was to broaden the participation of the science community and to enhance the utility of the data by making the data products rapidly available to the research community. The latter goal required a departure from the traditional Principal Scientist method of experiment science data management and the implementation of a new data ownership and processing data management regimen.

These objectives were achieved with outstanding success. Nimbus-7 carried nine instruments that generated the largest data set of any previous satellite program. The wide spectrum covered by the instruments and the derived data products is illustrated in Figure 22. Teams of scientists (Nimbus Experiment Teams) collaboratively developed the data product requirements and specifications, the algorithms for converting the measurements into geophysical parameters, the calibration of the sensor data, and the validation of the data products to initiate the production mode. The 9-instrument data products were routinely processed and distributed by a Nimbus Project-managed facility and three other institutional facilities to the large number of scientists and scientific organizations (over 45) engaged in the Earth science investigations and

the applications of the data. This new data management arrangement is described in the Nimbus-7 Data System section that follows.

Two new instruments made a distinctive impact on scientific knowledge of the Earth's environment and how to react to this knowledge for humanity's benefit. The predecessor to SBUV was BUUV that flew on Nimbus-4 already made its mark by being the first to measure ozone profiles from space and providing global data compared to the limited ozone data previously available from the ground Dobson network.

The Total Ozone Mapping Spectrometer (TOMS), that measured total ozone in the atmosphere, alerted the international community about the stratospheric ozone degradation resulting in a public awareness of this concern, and international agreements to curtail the cause of the degradation. The TOMS science program took on international interest after Nimbus TOMS data revealed the existence of ozone holes (large areas where the ozone level is below normal, safe levels) in the stratosphere that led to a 25-year and on-going international TOMS data collection program because of the concern about the impact of stratospheric ozone holes on people's health.

The Coastal Zone Color Scanner (CZCS) that measured ocean color for distinguishing oceanographic content and features evoked a remarkable interest in this new oceanographic tool. Scientist became capable of associating color radiance and their intensities with a wide variety of ocean life and oceanic constituents associated with oceanic productivity that affects the Earth's ecological balance and climate, with applications that impact commercial fishing. The results of these diverse CZCS scientific explorations and discoveries became the basis of most of the later oceanographic-discipline satellite experiments.

The Total Ozone Mapping Spectrometer (TOMS) had the capability to measure the total ozone and total sulfur dioxide, and aerosols (smoke, dust, and ash) in a column of air through the atmosphere as a function of the back-scattered ultraviolet radiation. The radiation, sequenced by a chopper, was measured at six wavelengths between 312 to 380 nm, with a 0.2 second exposure to the sensor at each of 35 cross-track scan positions. The TOMS scan-

ning mechanism took measurements across the orbital swath with a 50x50km resolution at nadir. TOMS was mounted together with the SBUV instrument so that it could share the SBUV solar illuminated diffuser plate used for calibration. The total ozone computed measurements were mapped daily. TOMS had a profound impact on world knowledge of ozone and the need for environmental control to protect ozone in the stratosphere. It revealed that very large stratospheric ozone holes develop annually in the Antarctic and periodically over populated sub-polar areas, causing international concern that led to the worldwide elimination/curtailment of CFCs that was destroying ozone. The TOMS measurement of this important environmental property was continued on the Soviet Meteor-3 spacecraft, on the Japanese ADEOS spacecraft, and currently operates on the GSFC TOMS Earth Probe (TOMS/EP) satellite. NOAA afternoon operational satellites carry a Solar Backscatter Ultraviolet Instrument (SBUV/2) that also measures backscatter radiation in the stratosphere for computing total ozone, but it does not have the scanning capability. Ground-based instruments distributed throughout the world also keep track of this vital total ozone statistic for the column of air above the ground measurement device, and are also used as a TOMS calibration standard reference.

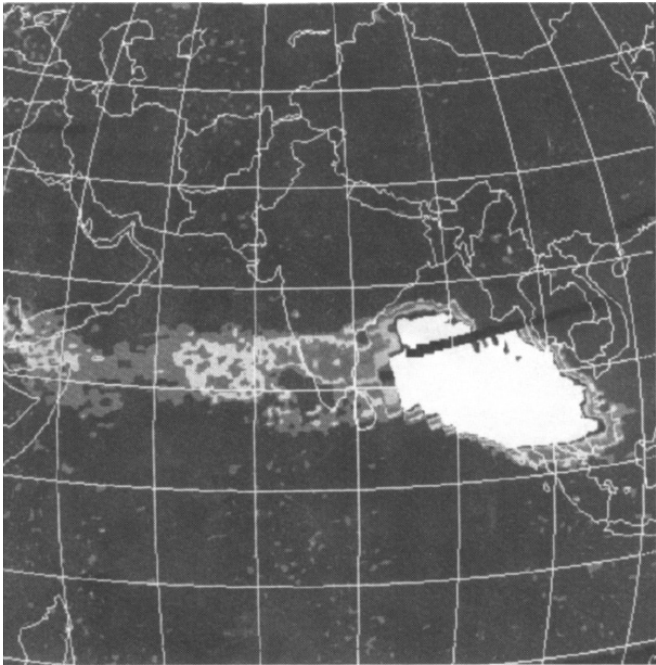
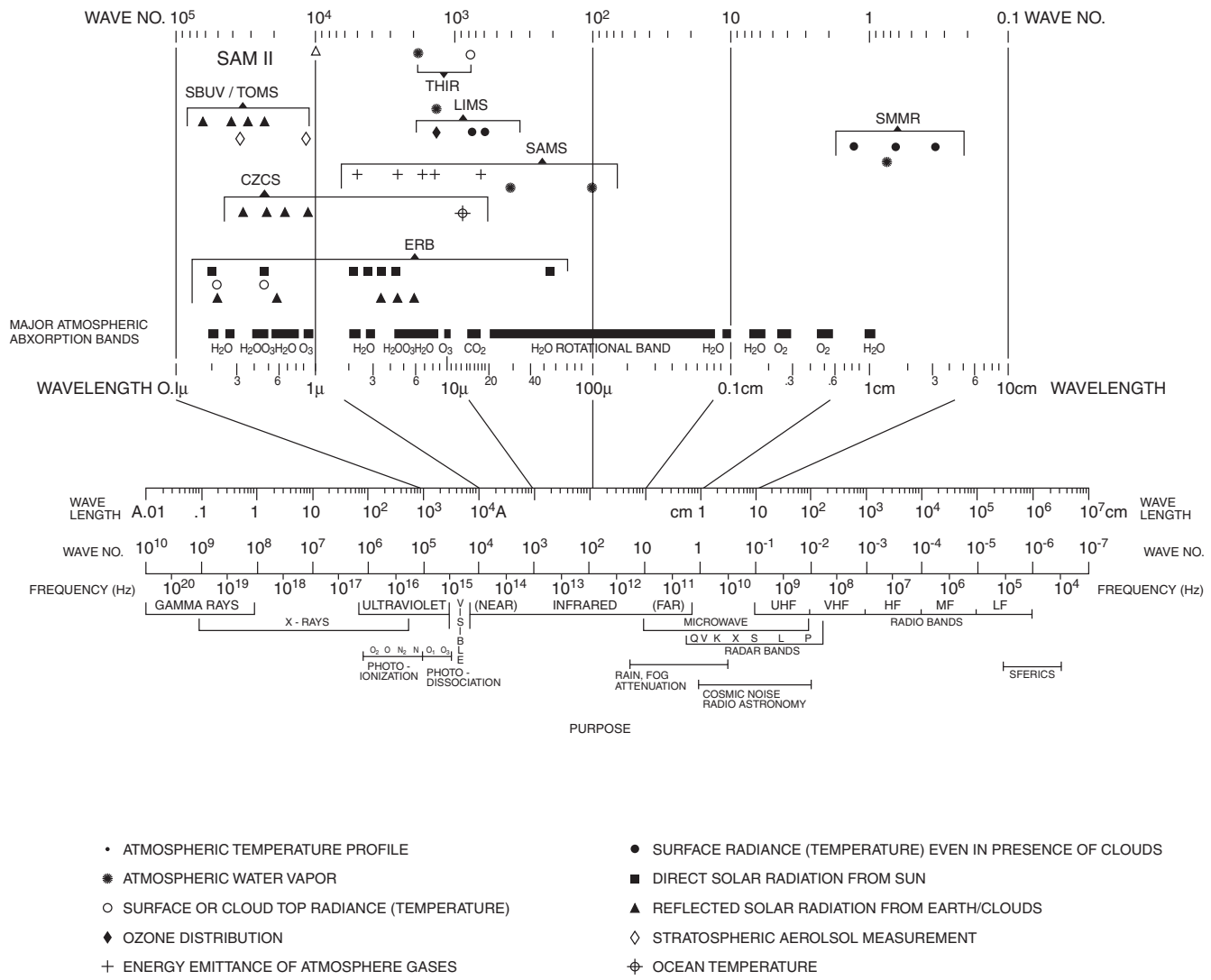


Figure 4: Volcanic SO2 cloud from Mount Pinatubo eruption taken by TOMS.



The Coastal Zone Color Scanner (CZCS) was a more intensive oceanographic measuring system than any previous oceanographic remote sensing instrument. CZCS is multi-spectral imaging radiometer with 6 channels in the 10.5-12.5 $\mu$ m and the 433-800 $\mu$ m spectral ranges, scanning 80° cross track with a 0.5° angular resolution. It measured the temperature of coastal waters and open ocean, mapped chlorophyll concentration and sediment distribution, detected pollution in coastal zones (including oil spills), and determined the nature of material suspended in the water, e.g., photoplankton, phytoplankton. CZCS, which operated for 8 years, was the primary oceanographic research data until the SeaWiFS satellite was launched in 1997.

Two instruments, the Scanning Multichannel Microwave Radiometer (SMMR) and the Solar Backscatter Ultraviolet (SBUV) were modified versions of instruments on earlier spacecraft. The objective was to continue the atmospheric, oceanographic, climatological, and meteorological ongoing research efforts with new data sets taken simultaneously.

The Scanning Multichannel Microwave Radiometer (SMMR) was an advanced, mechanically scanned version of the earlier ESMR instruments, with 10 channels operating at 6.33, 10.69, 18.00, 21.00, and 37Gh, and with both horizontal and vertical polarization. It looked conically 42° from nadir and at a constant earth incidence angle of 51°, and with an angular resolution of 0.8° to 4.2°. It was the first instrument to make more precise, all-weather observations of both global sea ice concentrations and type (age), and sea surface temperatures. In addition, it measured snow cover, soil moisture, rainfall, cloud water content, atmospheric water vapor over oceans, and sea surface winds.

The Solar Backscatter Ultraviolet (SBUV) instrument was similar to the BUV on Nimbus-4, with an improved diffuser plate configuration for relating the incoming UV radiation to the reflected UV radiation. It measured ozone profiles in the stratosphere and total ozone along the orbit track. The SBUV was mounted together with the TOMS instrument, sharing the solar illuminated diffuser plate used for calibration. An operational version of this instrument, SBUV/2, has been carried on NOAA afternoon polar orbiting spacecraft since 1984, which have the necessary sun angle for seeing the backscatter radiation.

Three new Nimbus-7 instruments, the Limb Infrared Monitoring of the Stratosphere (LIMS), the Stratospheric Aerosol Measurement II (Sam II), and the Stratospheric and Mesospheric Sounder (SAMS) concentrated on making stratospheric measurements.

The Limb Infrared Monitoring of the Stratosphere (LIMS) instrument design was based on the Nimbus-6 LRIR design concept but the objective was to study the stratosphere rather than the lower atmosphere. It measured temperature, ozone, water vapor, nitric acid and nitrogen dioxide. The detector was cooled to 63° K by a two-stage solid-cryogen cooler, the spectral range was 6.1-15.8 $\mu$ m. It scanned to 12° above the horizon.

The Stratospheric Aerosol Measurement II (Sam II), a mechanically scanned radiometer, operated at 1 $\mu$ m pointing at the sun during sunrise and sunset. It had an angular resolution of 0.01°. SAM II measured and mapped aerosol concentrations and optical properties in the polar stratosphere.

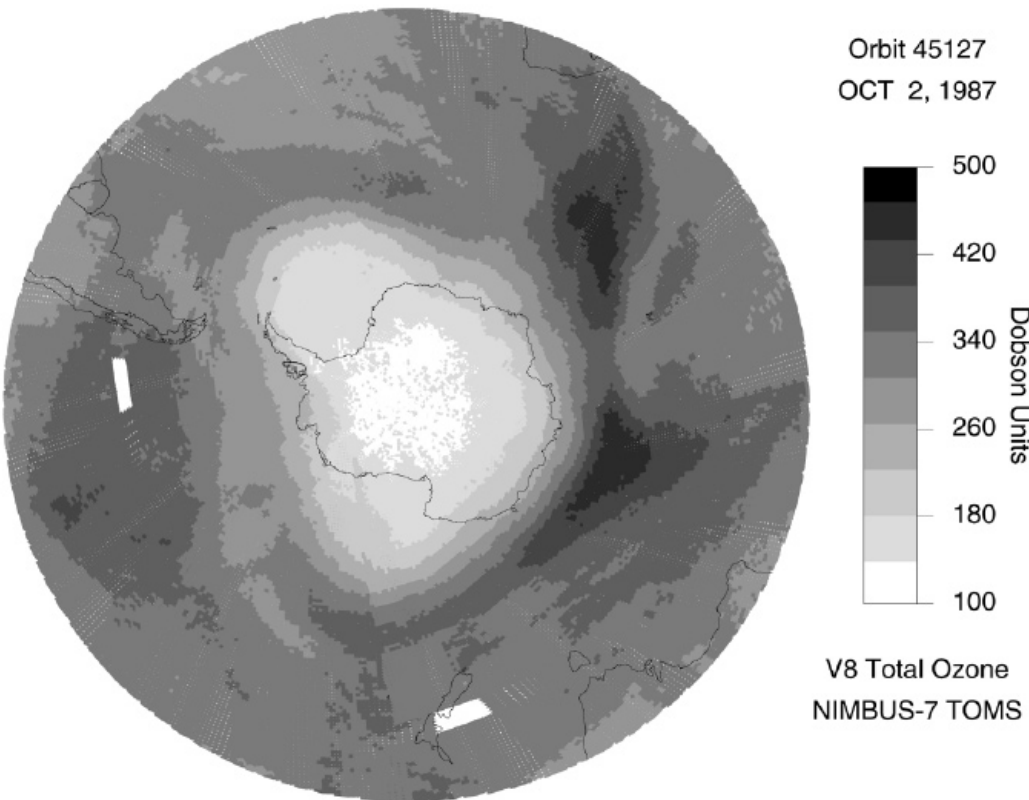
The Stratospheric and Mesospheric Sounder (SAMS), developed by Oxford University, UK, measured the distribution of temperature and select gases in the stratosphere and troposphere. It had 9 channels of data that operated in two spectral bands, 2.7-15 $\mu$ m and 25-100 $\mu$ m. It looked towards the horizon and scanned  $\pm$  15° about the central viewing direction that varied between 5° above the horizon to 9° below the horizon, with a 1.6° x 16° angular resolution.

The Earth Radiation Budget (ERB) was a duplicate of the Nimbus-6 ERB instrument for supporting the continuation of the Earth's energy budget and balance study.

The standard THIR instrument provided low-resolution terminator-to-terminator day and nighttime cloud and water vapor global data as meteorological condition reference information. It was also used to derive cloud temperature for data products.

Nimbus-7 operated for almost 15 years. This longevity is attributable to special orbital conditions that happened with Nimbus-7. The spacecraft was serendipitously launched in a favorable orbital plane position, i.e., the opposite side of the direct sun-line from the direction in which the plane normally drifts. That gave several years of

extra solar power lifetime before the orbital plane drifted to the nominal sun line plane and then started the normal drift away from the nominal sun line plane. Another contributory factor was the slower-than-normal drift away from the nominal sun line plane such that the array cell output was not reduced significantly by the cosine of the drift angle for several extra years. The solar cell degradation rate flattened out at a somewhat lower level than normal, which was another helpful condition. The use of magnetic torquers for attitude control rather than expendable gas jet-firings, which was the normal method, was another significant factor; the spacecraft lifetime would have been shortened if expendable gas was the only means available for unloading accumulated momentum. TOMS was operable in a degraded, but useful mode without the diffuser plate for several years until the end of operations; indirect means were developed to infer the TOMS data calibration. Spacecraft operation was shut down when TOMS failed; SAM II was the only other operative instrument.



**Figure 5 TOMS ozone hole observation.**

NIMBUS-7 DATA SYSTEM

The Nimbus-7 Project incorporated a major change in how NASA satellite science programs are conducted. The objective was to expand the science community participation in the scientific data development process and to make science data more readily and more rapidly available to a broader research community. It was a departure from the traditional Principal Investigator arrangement for managing the scientific data.

A Nimbus Experiment Team (NET) was established for each instrument that included approximately 3-8 members, experts in the related discipline, from around the country and internationally. The NET members defined the instrument data products, developed the data product algorithms, performed the original data evaluation to validate the data algorithms/products, and conducted long-term science research. Each instrument NET was assigned a Leader who was the scientist that promoted and supported the respective instrument development program.

Dr. Albert Fleig, the Nimbus-7 Project Scientist, coordinated the NET activity. He led the effort to standardize data products and formats, established the science data definition process and data validation approaches, and collaborated with the NET Leader to authorize the initiation of the individual data product production.

The Nimbus Observation Processing System (NOPS) was established for the Nimbus-7 processing consistent with the mission objectives. The production of the science data was allocated to facilities located where scientific support could be provided most effectively, i.e., LIMS at NCAR, SAMII at LaRC, SAMS at Oxford University, and the other instruments at GSFC. The Nimbus Project MDHS facility (with the use of the large data processing facility in Building 1) was responsible for the other six instrument data processing, the Level-0 processing, and the production of the Image Location Tapes (ILT).

The NET Leader for each instrument and the location of the processing facility for the respective Levels-1B, 2, and 3 instrument data is provided in Table-7. Measurements from the nine instruments on Nimbus-7 resulted in the largest data set produced by any previous satellite mission. The data is still being used to support scientific investigations.

The NET science role and the NOPS Project-facility processing arrangement were forerunners of the EOS Project science data development plan and the processing arrangement that consisted of Data Active Archive Centers (DAACs) for centralized, production processing, and distribution of instrument data.

**Processing plan:** The Project MDHS facility ingested the Level-0 (raw) data from all instruments. Orbital Image Location Tapes (ILT) were generated that contained the spacecraft ephemeris and computed attitude information, segregated by orbit, and were distributed to all Nimbus-7 processing facilities. MDHS generated a Level-1A tape for the low rate instruments that separated the data by orbits, chronologically. It contained the science data in raw telemetry units, and the respective instrument telemetry data calibrated to engineering units. LIMS, SAMII, SAMS, ERB, SMMR, BUV, and TOMS data was processed to Level 1B (located and calibrated observations in scientific units) in the MDHS. These data products were produced within the second day after the data was taken. The Level-1 data was converted to Level-2 (geophysical parameters) within the third day, converted to daily-mapped Level-3 products by the fourth day, and monthly Level-3 products by the end of the month.

The Level-2 and Level-3 data products were generated in a production mode after the algorithms were validated. The data was distributed routinely to the NET members and to the GSFC National Science Satellite Data Center (NSSDC) archive. NSSDC distributed requested data sets to the general science data user community.

Instrument	NET Leader	Organization	Levels-1B,-2,-3 Processing Facility
CZCS	Dr. Warren Hovis	NOAA NESDIS	GSFC/MDHS, Univ. of Florida
ERB	Dr. Herbert Jacobowitz	NOAA NESDIS	GSFC/MDHS
LIMS	Prof. John Gille	NCAR/Univ. of Colorado	NCAR
SAM II	Dr. Patrick McCormick	LaRC	LaRC
SAMS	Prof. Sir John Houghton	Oxford University, UK	Oxford University, UK
SBUV	Dr. Donald Heath	GSFC	GSFC/MDHS
SMMR	Dr. Per Gloersen	GSFC	GSFC/MDHS
THIR	No NET established		GSFC/MDHS
TOMS	Dr. Arlin Krueger	GSFC	GSFC/MDHS

Table 7 NET membership.

ACRONYMS

ACS	Attitude Control System
AMSU	Advanced Microwave Sounder Unit
APT	Automatic Picture Taking
AVCS	Advanced Vidicon Camera System
BUV	Backscatter Ultraviolet Spectrometer
CZCS	Coastal Zone Color Scanner
DAAC	Data Active Archive Centers
DARPA	Defense Advanced Research Projects Agency
ERB	Earth Radiation Budget
ESMR	Electrically Scanning Microwave Radiometer
ESSA	Environmental Satellite Service Administration
FWS	Filter Wedge Spectrometer
GSFC	Goddard Space Flight Center
HIRS	High Resolution Temperature Sounder
HRIR	High-Resolution Infrared Radiometer
I&T	Integration and Test
IDCS	Image Dissector Camera System
ILT	Image location Tape
IRIS	Infrared Interferometer Spectrometer
IRLS	Interrogation, Recording, Location System
ITPR	Infrared Temperature Profile Radiometer
LIMS	Limb Infrared Monitoring of the Stratosphere
LRIR	Limb Radiance Inversion Radiometer
MDHS	Meteorological Data Handling System
MIT	Massachusetts Institute of Technology
MRIR	Medium-Resolution Infrared Radiometer
MSS	Multispectral Scanner System
MUSE	Monitor of Ultraviolet Solar Energy
NASA	National Aeronautics and Space Administration
NCC	Nimbus Control Center
NEMS	Nimbus Experiment Microwave Spectrometer
NET	Nimbus Experiment Team
NOAA	National Oceanic and Atmospheric Administration
NOPS	Nimbus Observation Processing System
NSSDC	National Science Satellite Data Center
NWS	National Weather Service

PMR	Pressure Modulated Radiometer
RAMS	Random Access Measurement System
RMP	Rate Measuring Package
RTG	Radioisotope Thermoelectric Generator
SAM-II	Stratospheric Aerosol Measurement II
SAMS	Stratospheric and Mesospheric Sounder
SARSAT	Search and Rescue Satellite
SBUV	Solar/ Backscatter Ultraviolet Spectrometer
SCAMS	Scanning Microwave Spectrometer
SCMR	Surface Composition Mapping Radiometer
SCR	Selective Chopper Radiometer
SIRS	Satellite Infrared Radiometer Spectrometer
SMMR	Scanning Multi-channel Microwave Radiometer
T&DRE	Tracking and Data Relay Experiment
TDRS	Tracking and Data Relay Satellite
THIR	Temperature/Humidity Infrared Radiometer
TIROS	TIROS Operational Vertical Sounder
TOMS	Total Ozone Mapping Spectrometer
TOVS	TIROS Operational Vertical Sounder
TWERLE	Tropical Wind Energy Level Conversion and Reference Level Experiment
UK	United Kingdom
VTPR	Vertical Temperature Profile Radiometer

Notes

1. Instrument Information—I. <sup>1</sup> .S. Haas and R. Shapiro, “The Nimbus Satellite System”, American Institute of Aeronautics and Astronautics 1982

<sup>2</sup> I.S. Haas and R. Shapiro, “The Nimbus Satellite System”, American Institute of Aeronautics and Astronautics 1982

## **AEROSPACE INSTRUMENT RECORDS**

### *In Most Continuous Use*

#1	Nimbus-3 Infrared Interferometer Spectrometer (IRIS) Design	4/69–present
#2	Nimbus-4 Backscatter Ultraviolet Spectrometer (BUV) Design	4/70–present
#3	Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) Design	10/78–present

### *Most Number of Planetary Missions*

#1	Nimbus-3 Infrared Interferometer Spectrometer (IRIS) Design	7 Missions
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